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Evaluation of Hydraulic Cement-Based Materials for Rapid Repair of Airfield Spalls

by Reed B. Freeman, J. Kent Newman, Shelby D. Murray

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Prepared for U.S. Air Force Civil Engineering Support Agency

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Final report

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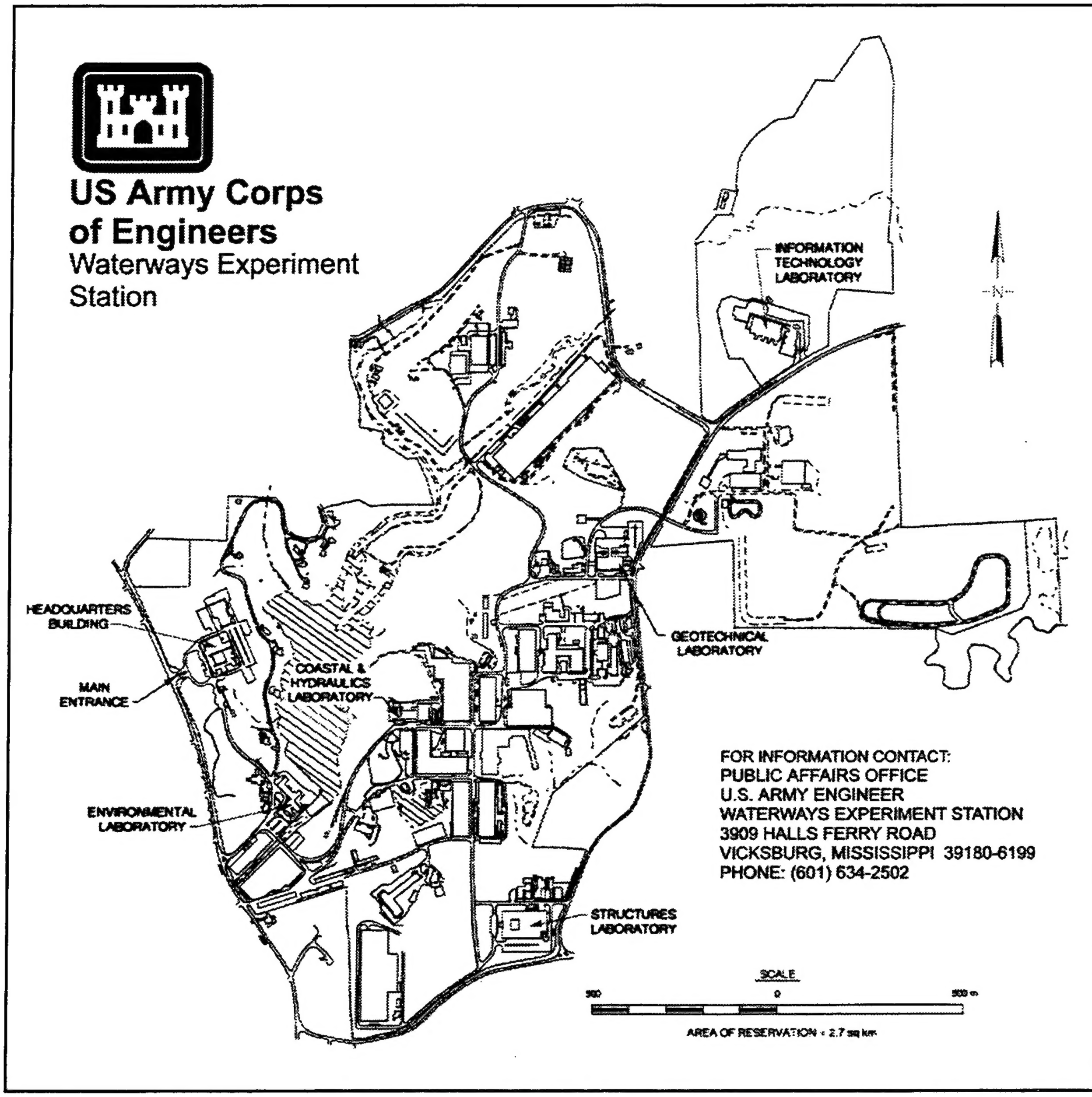

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Contents

Preface

The investigation documented in this report was sponsored by the U.S. Air Force Civil Engineering Support Agency, Tyndall Air Force Base, Florida. This work was conducted under Project Order No. F95-61, "New/Improved Technologies to Determine Applicability to the Air Force," the funding source for the Pavement Technology Application Program (PTAP). The PTAP Program Manager was LTC Randall Brown.

This study was conducted by personnel of both the Airfields and Pavements Division (APD), Geotechnical Laboratory (GL), and the Concrete Materials Division (CMD), Structures Laboratory (SL), at the U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, MS. This work was conducted from October 1995 through September 1996 under the project entitled, "Improved Repair Materials."

This study was conducted under the general supervision of Dr. W. F. Marcuson III, Director, GL. Direct supervision was provided by Dr. R. S. Rollings, Acting Chief, APD, and Mr. T. W. Vollor, Chief, Materials Analysis Branch (MAB), APD. Dr. Reed B. Freeman was the principal investigator for the project and authored the report along with Dr. J. Kent Newman and Mr. Shelby D. Murray, MAB. Personnel engaged in materials evaluation, in addition to the authors, included Messrs. T. Carr, W. Dorman, R. Felix, R. Graham, H. McKnight, MAB, and Messrs. M. Lloyd, D. Bean, M. Sykes, and J. Tom, CMD.

Dr. Robert W. Whalin was the Director of WES during the preparation of this report. COL Bruce Howard, EN, was Commander.

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Executive Summary

The Air Force strives to use durable materials for the repair of partial-depth spalls in portland cement concrete pavements. To keep abreast with the most promising repair materials, the Air Force evaluates several each year. This report provides evaluations for three hydraulic cement-based products: Five Star® Highway Patch, Rapid Set® Concrete, and Master Builders Set-45®.

The evaluation of these materials consisted of laboratory testing and a small-scale field test. The laboratory component evaluated workability, strength, compatibility with typical pavement concrete, and durability. The field component involved the use of these materials to repair 12 partial-depth spalls in a taxiway at Tyndall Air Force Base, Florida.

Relative comparisons of the materials included in this study resulted in the following recommendations. For room-temperature placements (approximately 25°C), Five Star® Highway Patch extended with 4.5 kg (10 lb) of aggregate is recommended, as long as the repair area can be closed to traffic for 3 to 6 hr. If the repair area needs to be opened to traffic in less than 3 hr, Set-45® extended with 4.5 kg (10 lb) of aggregate is recommended.

For low-temperature placements (approximately 2°C), Set-45® extended with 4.5 kg (10 lb) of aggregate is recommended. The repair area would need to be closed to traffic for 6 to 12 hr. The use of room-temperature mixing water or the use of insulation blankets over patches is encouraged to increase the rate of strength gain by retaining heat generated by hydration.

For high-temperature placements (approximately 35°C), Five Star® Highway Patch extended with 4.5 kg (10 lb) of aggregate and retarded with Summerset® admixture is recommended. The use of chilled, or at least room-temperature mixing water, is encouraged to extend working time. The repair area would need to be closed to traffic for 3 hr.

1 Introduction

The U.S. Air Force strives to use the most durable repair materials possible, including those for partial-depth spall repairs in concrete pavements. Keeping abreast with repair material technology is difficult because each year brings new patents and new companies. In addition, material formulations can change, without any change in brand name.

One method used by the U.S. Air Force to stay abreast with repair material technology is to evaluate several promising materials each year. The U.S. Army Engineer Waterways Experiment Station participates in this effort by providing materials research and evaluation services. This report, which is a product of these services, evaluates three hydraulic cement-based materials: Five Star® Highway Patch, manufactured by Five Star Products, Inc.; Rapid Set® Concrete, manufactured by CTS Cement Mfg. Co.; and Set-45®, manufactured by Master Builders, Inc. These materials were evaluated through both laboratory experimentation and field placements.

This report begins with descriptions of repair materials in Chapter 2. Laboratory evaluation procedures and results are presented in Chapters 3 and 4, respectively. Field placements are described in Chapter 5, including their performance after one year of service. A summary and recommendations that evolved from this study are provided in Chapter 6. Appendix A provides verbatim text from material packages to serve as a record of instructions that field-users would read. Appendices B through E provide detailed laboratory data. Appendix F provides summary fact sheets for the three evaluated repair materials.

2 Materials

This chapter provides a brief description of each repair material, along with a description of the aggregate used for extending their volume. In addition to Five Star® Highway Patch, Rapid Set® Concrete, and Set-45®, a description is provided for a product named Fondag Concrete. Although Fondag Concrete was not included in the initial experiment program for this study, it was available for demonstration at the field evaluation site. A verbatim description of the information printed on each material packaging is shown in Appendix A. Material fact sheets are provided in Appendix F for Five Star® Highway Patch, Rapid Set® Concrete, and Set-45®.

Five Star® Highway Patch

Five Star® Highway Patch is packaged as a dry mortar and is available in 22.7 kg (50 lb) bags. Five Star® Highway Patch contains an hydraulic cement, for which a patent is pending, and siliceous sand. All particles in the as-received material are finer than 2.36 mm (No. 8 sieve), as shown in the sieve analysis in Table 2.1. In the year 1996, the cost of this material was approximately $20 per bag.

Five Star Products markets a set retarding admixture called Summerset®. This admixture, which is an organic acid, is available in liquid form. The product can be shipped in tubes that contain 15 cc (1/2 fl oz) of material, which makes it convenient for use with the 22.7 kg (50 lb) bags of Five Star® Highway Patch. In the year 1996, the cost of this material was approximately $2.50 per tube.

Rapid Set® Concrete Mix

Rapid Set® Concrete Mix is packaged dry in 27.2 kg (60 lb) bags. It contains Rapid Set® Cement, which is a hydraulic cement with high chemical contents of alumina and sulfur trioxide. The manufacturer states that its composition is similar to that of ASTM C 845 (ASTM 1995a) Type K expansive cement, which is used in shrinkage-compensating concrete. Rapid Set®

Table 2.1 Sieve Analysis for Five Star® Highway Patch	
Sieve Size	**Percent Passing**
12.5 mm (1/2 in.)	100
9.5 mm (3/8 in.)	100
4.76 mm (No. 4)	100
2.36 mm (No. 8)	100
1.18 mm (No. 16)	94
0.60 mm (No. 30)	51
0.30 mm (No. 50)	44
0.15 mm (No. 100)	41

Concrete Mix also contains siliceous sand and crushed limestone aggregate particles up to and including the 12.5 mm (1/2 in.) size. A sieve analysis for the as-received material is shown in Table 2.2. Forty percent of this material can be considered coarse aggregate (particles larger than the No. 4 sieve). In the year 1996, the cost of this material was approximately $15 per bag.

The CTS Company markets a set retarding admixture called Set Control™ This admixture, which is an organic (citric) acid, is available in dry powder form. The product can be shipped in packets that contain approximately 30 gm of material, which makes it convenient for use with the 27.2 kg (60 lb) bags of Rapid Set® Concrete Mix. In the year 1996, the cost of this material was approximately $1 per packet.

Table 2.2 Sieve Analysis for Rapid Set® Concrete	
Sieve Size	**Percent Passing**
19.1 mm (3/4 in.)	100
12.5 mm (1/2 in.)	89
9.5 mm (3/8 in.)	76
4.76 mm (No. 4)	60
2.36 mm (No. 8)	58
1.18 mm (No. 16)	57
0.60 mm (No. 30)	50
0.30 mm (No. 50)	38
0.15 mm (No. 100)	30

Set-45®

Set-45® is packaged as a dry mortar and is available in 22.7 kg (50 lb) bags. Set-45® contains a magnesium phosphate cement and siliceous sand. All particles in the as-received material are finer than 2.36 mm (0.094 in.), as shown in

the sieve analysis in Table 2.3. In the year 1996, the cost of this material was approximately $25 per bag.

Table 2.3
Sieve Analyses for Set-45® and Set-45® Hot Weather

Sieve Size	Percent Passing	
	Set-45®	Set-45® Hot Weather
12.5 mm (1/2 in.)	100	100
9.5 mm (3/8 in.)	100	100
4.76 mm (No. 4)	100	100
2.36 mm (No. 8)	100	100
1.18 mm (No. 16)	72	73
0.60 mm (No. 30)	58	54
0.30 mm (No. 50)	42	40
0.15 mm (No. 100)	34	28

Master Builders markets a special formulation of Set-45® designed for placements in hot weather. The product is called Set-45® Hot Weather and is available in 22.7 kg (50 lb) bags, similar to the standard formulation of Set-45®. The gradation of Set-45® Hot Weather is similar to that of Set-45®, as shown in Table 2.3. Among other differences, the hot weather formulation contains boric acid, which retards hydration reactions. In the year 1996, the cost of this material was approximately $45 per bag.

Fondag Concrete

Fondag concrete is packaged dry in 22.7 kg (50 lb) bags. It contains a cement that produces a large proportion of calcium aluminates upon hydration. It also contains fine and coarse aggregates that are synthetic, hard, dense, and nonporous. This material was used in the field but was not included in the original laboratory test plan. Therefore, a sieve analysis is not available. In the year 1996, the cost of this material was approximately $15 per bag.

Aggregate

The aggregate used for extending the volume of mortar materials was a siliceous river gravel. This type of aggregate met the requirements for both Five Star® Highway Patch and Set-45®. The aggregate was obtained from within the state of Mississippi. It was rounded and smooth with a bulk specific gravity (SSD basis) and an absorption capacity of 2.55 and 2.5 percent, respectively. Since the repair materials specified the use of "clean" aggregates for

extending volume, all gravel particles finer than 4.76 mm (0.187 in.) were removed. A sieve analysis for the resulting river gravel aggregate is shown in Table 2.4. The loose unit weight for the clean aggregate was 1440 kg/m^3 (90 lb/ft^3).

Table 2.4
River Gravel Used for Extending Mixtures

Sieve	Percent Passing
12.5 mm (1/2 in.)	100
9.5 mm (3/8 in.)	76.4
4.76 mm (No. 4)	0

3 Laboratory Evaluation Program

The laboratory evaluation program was designed to consider workability, strength, compatibility, and durability characteristics of the repair materials. Workability considerations included set-time and slump tests. Set-time tests were performed on fines (-#100 sieve) that were removed from the bags by sieving. Slump tests were performed on trial mixtures to determine the maximum practical volume extension with aggregate, while maintaining reasonable workability and finishability. Selected mixtures were also monitored for slump loss versus time.

Strength considerations included flexural strength, compressive strength, and bond strength. Flexural strength tests were performed at curing durations of 3 hr and 7 days, at a placement and curing temperature of 25°C (77°F). Compressive strength tests were performed at curing durations of 3 hr, 1 day, 7 days, and 28 days, at placement and curing temperatures of 2°C (35°F), 25°C (77°F), and 46°C (115°F). Bond tests were performed at a curing duration of 7 days for conditions of placement against both a dry and wet substrate.

Compatibility considerations included modulus of elasticity and coefficient of thermal expansion. Modulus of elasticity and coefficient of thermal expansion were considered compatibility factors because large differences between these properties for a repair material and its substrate concrete will reduce the longevity of the repair.

Durability considerations included resistance to freeze-thaw cycles, drying shrinkage, and expansion in water. Drying shrinkage and expansion in water were considered durability factors because excessive movements can cause repairs to dislodge.

Particle Size Distribution

A single bag of each material was set aside for a gradation analysis. Each entire bag was sieved in accordance with ASTM C 136 (ASTM 1995b), "Sieve Analysis of Fine and Coarse Aggregates." Sieve analyses and general

statements concerning aggregate types were presented in Chapter 2. Material passing the #100 sieve was saved for use in the set time studies.

Specimen Fabrication

Mixing and curing procedures followed the guidelines printed on the repair material packages. Specimen compaction procedures adhered to the requirements in ASTM C 192 (ASTM 1995b), "Making and Curing Concrete Test Specimens in the Laboratory," and ASTM C 109 (ASTM 1995a), "Compressive Strength of Hydraulic Cement Mortars (Using 50-mm or 2-in. Cube Specimens)."

Water contents and the use of retarding admixtures followed recommendations on the material packages. The temperature of mixing water was changed in order to facilitate material placement. These changes remained reasonable, so that they could be achieved in the field. Mixture characteristics are shown in Table 3.1. None of the materials specified adjustments in water content or retarder dosage with the use of aggregates.

A mortar mixer was used for producing all repair materials. The mortar mixer was dampened before each mix, in accordance with manufacturer recommendations. If an admixture was needed, it was dissolved in the mixing water. The sequence with which the concrete materials were added to the mixer was specified by some manufacturers in order to promote the most efficient and thorough mixing. The sequence was not the same for each material. Mixing time varied between 1 and 5 min.

Table 3.1
Mixture Characteristics

Mixture	Placement and Curing Temperature		
	2°C	25°C	46°C
Five Star® Highway Patch [each bag weighed 22.7 kg (50 lb)]			
Water content per bag	2840 ml	2840 ml	2840 ml
Water temperature	2°C	25°C	25°C
Retarder dosage	none	none	45 ml
Rapid Set® Concrete [each bag weighed 27.2 kg (60 lb)]			
Water content per bag	3790 ml	3790 ml	3790 ml
Water temperature	2°C	25°C	25°C
Retarder dosage	none	none	45 gm
Master Builders Set-45® [each bag weighed 22.7 kg (50 lb)]			
Water content per bag	1900 ml	1900 ml	N/A
Water temperature	2°C	25°C	N/A
Retarder dosage	none	none	N/A
Set-45® Hot Weather [each bag weighed 22.7 kg (50 lb)]			
Water content per bag	N/A	1800 ml	1800 ml
Water temperature	N/A	25°C	2°C
Retarder dosage	N/A	none	none

Curing was performed in accordance with recommendations on the repair material packages. Rapid Set® Concrete and Set-45® required no special curing precautions, while Five Star® Highway Patch needed to be kept moist for at least 30 min once it started to harden.

Test Procedures

Set-time

Set-time tests provide an indication of the rate at which hydraulic cements stiffen and harden. These tests are useful for relative comparisons between cements and they are useful for monitoring the quality of cement as it is produced. However, there is no distinct relationship between set-time for cement and the rate of slump loss for concrete.

Set-time tests are typically performed on samples of cement, without any fine aggregates or mineral dust. Since each of the repair materials studied were purchased in the prepackaged form of mortar or concrete, the cement component needed to be removed by sieving. Removing all particles finer than the No. 200 (0.075 mm) sieve would be appropriate because cement particles are typically finer than this size. However, due to difficulties in sieving large quantities of dry material through the No. 200 sieve, a No. 100 sieve was used in its place. Material finer than the No. 100 sieve was used for the set-time tests in this study. This material consisted primarily of cement, but unavoidably also contained some mineral dust.

Initial and final set-times were determined in accordance ASTM C 191 (ASTM 1995a), "Time of Setting of Hydraulic Cement by Vicat Needle." This test begins with the determination of the amount of water that causes the cement to assume a "normal consistency." The test used for determining this amount of water was ASTM C 187 (ASTM 1995a), "Normal Consistency of Hydraulic Cement." This test involves adding various amounts of water to 650 g of cement (or fines). The paste is mixed, secured in a truncated cone-shaped mold, and is then subjected to penetration by a standard rod that weighs 300 g and is 10 mm in diameter. The amount of water that produces normal consistency is that which allows the rod to penetrate 10 $\pm$ 1 mm in 30 sec.

To perform set-time tests, cement paste is reproduced with normal consistency. The paste is secured in the same mold as that used for consistency testing and is covered with a moist towel to prevent drying. At various times, the paste is subjected to penetration by a needle that weighs 300 g and is 1 mm in diameter. The first penetration should proceed 40 mm to the base of the molded paste specimen. Initial set is defined as the time when penetration was limited to 25 mm in 30 sec. Final set is defined as the time when the needle does not sink visibly into the paste.

Slump

The slump test provides an indication of the consistency of fresh (unhardened) concrete. It is also the most popular method for judging concrete workability because it provides a measure of the resistance of concrete to flowing under its own weight. This test method is not considered applicable to non-plastic or non-cohesive concrete. Concrete with a slump less than 13 mm (1/2 in.) may not be adequately plastic and concrete with a slump greater than about 230 mm (9 in.) may not be adequately cohesive for this test to have significance.

This test was performed in accordance with ASTM C 143 (ASTM 1995b), "Slump of Hydraulic Cement Concrete." The test involved filling a truncated cone that is 305 mm (12 in.) tall, 203 mm (8 in.) in diameter at its base, and 102 mm (4 in.) in diameter at its top. The truncated cone is filled in three equal-volume layers, rodding each layer 25 times with a 16-mm (5/8-in.) diameter rod. After screeding off excess concrete, the mold is lifted vertically with a steady motion that takes approximately 5 sec. Slump should then be measured immediately by determining the vertical distance that the concrete has subsided, relative to its original height of 305 mm (12 in.).

Flexural strength

Flexural strength was measured by third-point loading on 152x152x508-mm (6x6x20-in.) beams. Specimens were cured in accordance with manufacturer recommendations and tests were performed in accordance with ASTM C 78 (ASTM 1995b), "Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)." Tensile strength in flexure, or modulus of rupture, was calculated as:

$$R = \frac{P \cdot l}{b \cdot d^2}$$

where

R = modulus of rupture, MPa (psi)

P = maximum applied load, N (lbf)

l = span length, mm (in.)

b = average width of specimen, mm (in.)

d = average depth of specimen, mm (in.)

Compressive strength

Compressive strength is often used as a measure of the general quality of concrete. Compressive strength is easy to measure and it is positively related to several other desirable properties, such as tensile strength and stiffness. For

this study, compressive strength was measured with mortar and concrete cubes. The cubes were all 50 mm (2 in.) in edge length. This size specimen could accommodate all the mortar and concrete mixtures used in this study. According to ASTM C 192 (ASTM 1995b), "Making and Curing Concrete Test Specimens in the Laboratory," the minimum cross-sectional dimension of the mold should be at least three times the nominal maximum size of the concrete aggregate. In the concrete industry, nominal maximum size typically refers to the sieve size that is one level larger than the sieve upon which at least 15 percent of the particles is cumulatively retained. The largest aggregate used for concrete in this study had a nominal maximum size of 13 mm (1/2 in.), which is less than one-third the minimum cube dimension.

Specimens were cured in accordance with manufacturer recommendations. Compressive strength tests were performed at a rate that caused failure within 20 to 80 sec, in accordance with ASTM C 109 (ASTM 1995b), "Compressive Strength of Hydraulic Cement Mortars (Using 50-mm or 2-in. Cube Specimens)." Compressive strength was calculated as ultimate load divided by the cross-sectional area of the cube, which was 0.0026 mm^2 (4 $in.^2$).

Bond strength

Bond strength was measured by a modified version of ASTM C 882 (ASTM 1995b), "Bond Strength of Epoxy-Resin Systems Used with Concrete by Slant Shear." As preparation for the bond tests, ordinary portland cement concrete specimens were cast within 76-mm (3-in.) diameter cylinder molds and against steel dummy sections. The dummy sections and the complementary portland cement concrete specimens had dimensions shown in Figure 3.1. The portland cement concrete specimens were intended to represent substrate concrete, so they were designed to achieve compressive strengths of 28 to 34 MPa (4,000 to 5,000 psi) after 28 days of moist curing. After 28 days of curing, some of the specimens remained in the water and some were removed for drying. The repair material bond test then proceeded in a fashion that simulated either bond against a wet substrate or bond against a dry substrate. After casting a repair material against the conditioned portland cement concrete section, to form a complete 76 x 152-mm (3 x 6-in.) cylinder, curing proceeded as specified by the manufacturer of the repair material. The degree of bond was measured by subjecting the composite cylinder to a compressive force, in accordance with procedures described in ASTM C 39 (ASTM 1995b), "Compressive Strength of Cylindrical Concrete Specimens." These procedures included a load rate of 0.14 to 0.34 MPa/sec (20 to 50 psi/sec). Bond strength was calculated as the force divided by the elliptical bond area, which was equal to 9,116 mm^2 (14.1 $in.^2$).

Modulus of elasticity

Modulus of elasticity was determined for cylinders of dimensions 76 x 52-mm (3 x 6-in.) after 7 days of curing in accordance with manufacturer recommendations. The cylinders were fitted with an external, electronic extensiometer and were loaded at a rate of 0.21 to 0.28 MPa/sec (30 to

40 psi/sec). A data acquisition system monitored stress and strain during the compression test. Modulus of elasticity was calculated in accordance with ASTM C 469 (ASTM 1995b), "Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression:"

$$E = \frac{S_2 - S_1}{\epsilon_2 - 0.000050}$$

where

E = chord modulus of elasticity, MPa (psi)

S_2 = stress corresponding to 40 percent of ultimate load, MPa (psi)

S_1 = stress corresponding to 50 millionths, MPa (psi)

ϵ_2 = longitudinal strain produced by stress S_2, mm/mm (in./in.)

Coefficient of thermal expansion

The coefficients of thermal expansion were measured in accordance with CRD-C 39, "Test Method for Coefficient of Linear Thermal Expansion of Concrete." Prisms of dimensions 76x76x286 mm (3 x 3 x 11-1/4 in.) were cast with a stainless steel gage stud embedded in each end. The prisms were cured for 28 days in accordance with manufacturer recommendations and were then immersed in room temperature water. Once expansion due to absorption ended, the test was initiated. The prisms were immersed in hot water [60°C (140°F)] for a sufficient length of time to stabilize (2 to 3 hr). After measuring their length under hot conditions, the prisms were placed back in the room temperature water. The following day the prisms were placed in cold water [4°C (40°F)] and were permitted time to stabilize (2 to 3 hr) before measuring their lengths. The coefficient of linear thermal expansion was calculated as:

$$\gamma = \frac{\Delta l}{g \cdot \Delta T}$$

where

γ = coefficient of linear thermal expansion, mm/mm/°C (in./in./°F)

Δl = change in length from hot bath to cold bath, mm (in.)

g = gage length, mm (in.)

ΔT = change in temperature from hot bath to cold bath, °C (°F)

Freeze-thaw resistance

The resistance of repair materials to freeze-thaw damage was tested in accordance with ASTM C 666 (ASTM 1995b), "Resistance of Concrete to Freezing and Thawing," Procedure A. Prisms were cast in molds of dimensions 76 x 102 x 406 mm (3 x 4 x 16 in.). The prisms were cured for 7 days in accordance with manufacturer recommendations and were then immersed in water for another 21 days to ensure saturation. After soaking, the prisms were subjected to cycles of freezing and thawing while surrounded by a film of water 1 mm to 3 mm (1/32 in. to 1/8 in.) thick. Prior to initiating the test and every 10 to 30 cycles thereafter, the prisms were weighed and were tested for resonant frequency of surface waves. The change in resonant frequency squared was assumed to be approximately proportional to the change in dynamic modulus, so at any time during the test, a relative dynamic modulus could be calculated (relative to dynamic modulus at the beginning of the test). The test was continued until the specimen had either been subjected to 300 freeze-thaw cycles or until it had suffered a 40 percent loss in resilient modulus, whichever occurred first. Results were presented as a durability factor:

$$DF = \frac{P \cdot N}{300}$$

where

DF = durability factor of the test specimen

P = relative dynamic modulus of elasticity at N cycles, percent

N = number of cycles at which P reaches 60 percent or 300, whichever is less

Drying shrinkage and expansion in water

The prisms used for these tests were similar to those used for the thermal expansion test. The prisms had dimensions 76 x 76 x 286 mm (3 x 3 x 11-1/4 in.) and a stainless steel gage stud was cast into each end. For both tests, the specimens were demolded three hours after casting and an initial length was obtained. Lengths were measured using the gage studs and in accordance with ASTM C 490 (ASTM 1995b), "Use of Apparatus for the Determination of Length Change of Hardened Cement Paste, Mortar, and Concrete." For the drying shrinkage test, further curing was performed in air at 23°C (73°F) and at relative humidity 50 percent. For the expansion test, further curing was performed in lime-saturated water at 23°C (73°F). These curing procedures are in accordance with ASTM C 157 (ASTM 1995b), "Length Change of Hardened Hydraulic-Cement Mortar and Concrete." Determinations of length change for the prisms were made at the following durations of cure: 1, 3, 7, 14, and 28 days. All calculations for percent

change in length used 254 mm (10 in.) as the gage length. This length is considered to be the length between the closest ends of the gage studs.

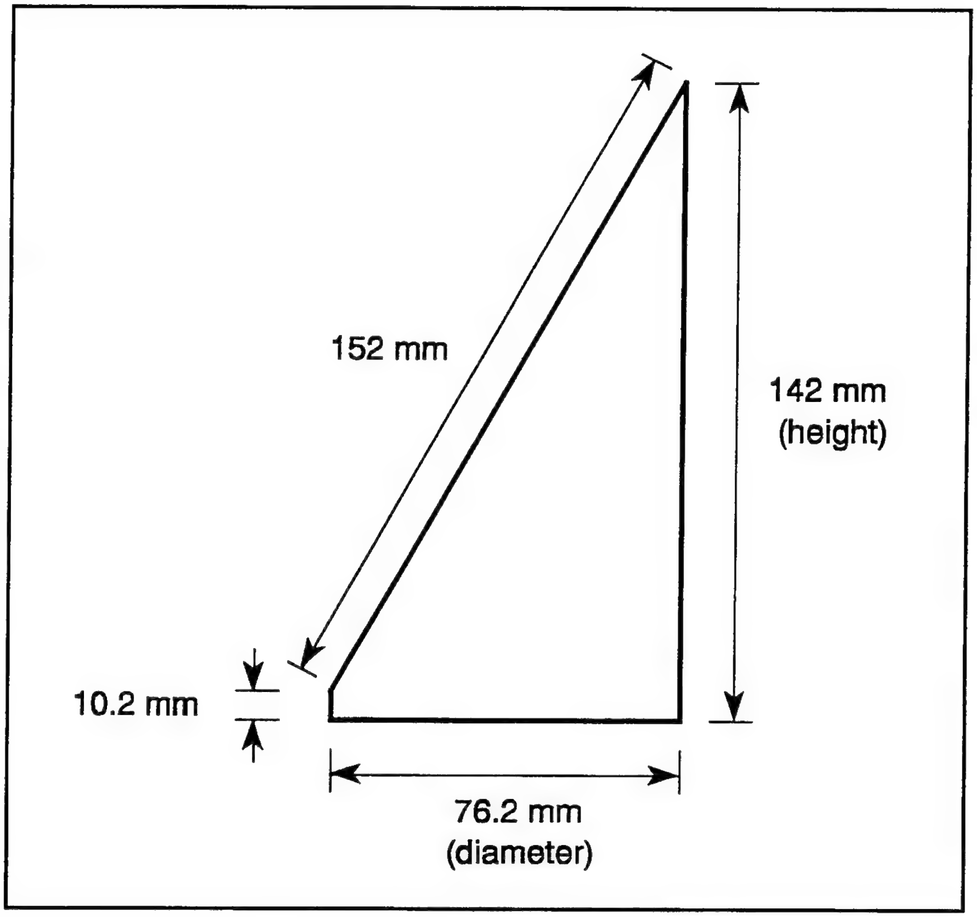

Figure 3.1. Cross-section of dummy section

4 Laboratory Evaluation Results

Results are organized and presented by material properties. All material types are discussed for each property to permit comparisons. Detailed laboratory data are presented in Appendices B through E, organized in the following order: workability characteristics, strength properties, compatibility characteristics, and durability properties. This chapter will begin with a presentation of particle size distributions and will then follow an order similar to the appendices. Summaries for each material type are provided in the form of material fact sheets in Appendix F.

Particle Size Distribution

As we would expect, the Rapid Set® Concrete has a coarser particle size distribution than the other materials in the as-received condition (Figure 4.1). Five Star® Highway Patch, Set-45®, and Set-45® Hot Weather can be considered prepackaged mortars. Five Star Highway Patch is the finest material in its prepackaged condition. All the materials had approximately 30 to 40 percent passing the No. 100 sieve.

Normal Consistency and Set Time

The water/fines ratio (normally reported as water/cement ratio) required to achieve "normal" consistency ranged from 0.2 to 0.4, as shown in Figure 4.2. Rapid Set® fines needed more water than Five Star® or Set-45®. Adding retarders to Five Star® and Rapid Set® decreased the amount of water needed. Using the hot weather formulation of Set-45® had the same effect.

Initial set times for all three materials ranged from 11 to 12 min when retarders were not used, as shown in Figure 4.3. The use of retarders or the hot weather formula extended initial set times to the range of approximately 40 to 60 min.

Final set times for all three materials ranged from 12 to 17 min when retarders were not used, as shown in Figure 4.4. The use of retarders or the hot weather formula extended final set times to the range of approximately 50 to 80 min.

Slump

The first step in the slump analysis was to determine the maximum amount of aggregate that could be used to extend the Five Star® and Set-45® mixtures. In order to keep the mixtures workable for shovel and wheelbarrow-type operations, the slump was set at approximately 23 mm (9 in.). This requirement permitted comparisons between material types at equal workabilities because the slump for Rapid Set® Concrete was also 23 mm (9 in.).

For both Five Star® and Set-45®, the maximum amount of aggregate that could be used per bag of material was found to be 4.5 kg (10 lb). As aggregate contents increased to greater than 4.5 kg, measured slumps for both materials decreased to less than 23 mm, as shown in Figure 4.5. The loss in workability with high aggregate contents was more substantial for Five Star® than for Set-45®. For consistency of proportions, the Set-45® Hot Weather mixtures were committed to the same aggregate extension as the regular formulation of Set-45® (i.e. 4.5 kg).

With the concrete mixture proportioning completed, we compared percentages of coarse aggregate for the different materials. With the consideration that coarse aggregate particles consist of those larger than the No. 4 sieve, the Rapid Set® Concrete had about 40 percent coarse aggregate by mass, while Five Star® and Set-45® concretes had only about 17 percent coarse aggregate by mass (Table 4.1). This difference was at least partially attributable to the fact that Rapid Set® Concrete had a maximum aggregate size of 19 mm, while the Five Star® and Set-45® materials had maximum aggregate sizes of 13 mm. High volumes of coarse aggregate can be beneficial in terms of drying shrinkage.

The length of time permitted for concrete placement in the field was estimated by measuring slump until it dropped below 8 mm (3 in.). The concrete mixtures included Five Star® extended with 4.5 kg of aggregate, Rapid Set® Concrete, and Set-45® extended with 4.5 kg of aggregate. While Five Star® and Rapid Set® provided about 40 min of working time, Set-45® provided only 14 min, as shown in Figure 4.6.

Retarding admixtures were expected to improve concrete workability at room temperature, especially after finding that pastes needed less water for "normal" consistency with the use of retarders. The anticipated benefit of retarders, however, was not found for Five Star® or Rapid Set®. At room temperature, the retarders did not increase initial slump and they did not extend the working time (Figure 4.6). The use of Set-45® Hot Weather at room temperature, however, improved initial slump and extended the working time from 14 min to about 50 min.

Table 4.1
Sieve Analyses for Concrete Materials

Sieve Size	Percent Passing			
	Five Star®	Rapid Set®	Set-45®	Set-45® (HW)
3/4 in. (19.1 mm)	---	100	---	---
½ in. (12.5 mm)	100	89	100	100
3/8 in.(9.5 mm)	96	76	96	96
No. 4 (4.76 mm)	83	60	83	83
No. 8 (2.36 mm)	83	58	82	83
No. 16 (1.18 mm)	78	57	60	61
No. 30 (0.60 mm)	43	50	49	45
No. 50 (0.30 mm)	37	38	35	33
No. 100 (0.15 mm)	34	30	28	23

Flexural Strength

The flexural strengths of the repair materials, as measured by 152 x 152 x 508-mm (6 x 6 x 20-in.) beams cast and cured at 25°C, were all similar. Flexural strengths at 7 days ranged from 3.5 MPa to 3.9 MPa (510 psi to 560 psi), as shown in Figure 4.7. The proportion of 7-day strengths gained after 3 hr ranged from 85 percent to 96 percent.

Compressive Strength

The compressive strengths of the repair materials, as measured by 51-mm cubes cast and cured at 25°C, varied between mixtures more than the flexural strengths. Strengths at 28 days ranged from to 46 to 69 MPa (6680 to 9930 psi), as shown in Figure 4.8. The strength of the mixture produced with neat Set-45® Hot Weather was substantially lower than the other mixtures. Strengths at 3 hr varied between mixtures even more than strengths at 28 days. They ranged from 3.0 to 45 MPa (440 to 6550 psi). The Set-45® mixtures had the highest 3-hr strengths, while the Five Star® and Set-45® Hot Weather mixtures had the lowest 3-hr strengths.

When cast and cured at 2°C, the compressive strengths of the repair materials were lower than those cast and cured at 25°C, even after 28 days of curing. Set-45® had the highest strength at 1 day, while Rapid Set® had the highest strength at 28 days, as shown in Figure 4.9. Set-45® was the only mixture that could be demolded at 3 hr; it had attained a strength of 8.8 MPa (1280 psi). All the other mixtures could not be demolded until 6 hr or later. The extended Five Star® mixture had the lowest strength at 24 hr: 9.1 MPa (1320 psi).

The Rapid Set® Concrete packages specified a decrease in mixing water content for low placement temperatures. As compared to 3785 ml (4 qt) of

water per bag at room temperature, 2840 ml (3 qt) were permitted for placement temperatures less than 10°C (50°F). This amount of water produced a mixture that had insufficient workability. Therefore, the amount of mixing water used at the low placement temperature was adjusted to be the same as that used at room temperature.

When cast and cured at 46°C, the compressive strengths of the repair materials at 3 hr were higher than those cast and cured at 25°C, as shown in Figure 4.10. In most cases, however, casting and curing at the high temperature decreased 28-day strengths. Although the original intention was for all mixing water to be at 25°C, the Set-45® Hot Weather mixtures had less than 10 min of working time. Therefore, these mixtures had to be produced with mixing water at 2°C.

The Rapid Set® Concrete packages specified an increased mixing water content for high placement temperatures. As compared to 3785 ml (4 qt) of water per bag at room temperature, 5200 ml (5.5 qt) were recommended for placement temperatures above 38°C (100°F). This recommended water content was found to be excessive; measured slumps were greater than 25 mm (10 in.) and compressive strengths were approximately one-half those for room-temperature mixtures. Therefore, the amount of mixing water used at the high placement temperature was the same as adjusted to be the same as that used at room temperature.

Bond Strength

Bond strength was measured at 7 days for specimens cast and cured at 25°C. Bond strength ranged from 6.1 to 30 MPa (880 to 4330 psi), as shown in Figure 4.11. Five Star® Highway Patch performed well in terms of bond strength [greater than 20 MPa (2900 psi)], with its best performance associated with a dry substrate. Set-45® also attained bond strengths on the order of 20 MPa (2900 psi), as long as the substrate was wet. Rapid Set® Concrete and Set-45® Hot Weather generally attained bond strengths on the order of 15 MPa (2200 psi). The bond strength of Set-45 Hot Weather was inconsistent, even under laboratory conditions. Extension of repair materials with aggregate did not have a consistent effect on bond strength.

Modulus of Elasticity

Modulus of elasticity for all repair materials was on the order of normal concrete, ranging approximately from 20 to 40 GPa (2.9 to 5.8 x 10^6 psi) after 7 days of curing at 25°C (Figure 4.12). Rapid Set® Concrete had the lowest stiffness, perhaps due to its aggregate type. Rapid Set Concrete included a crushed limestone, while the other materials were extended with river gravel. Extension of the mortar materials with aggregate did not have a consistent or substantial effect on stiffness.

Coefficient of Thermal Expansion

All the repair materials were similar in terms of coefficient of thermal expansion, ranging from 12 to 13 x 10^{-6} mm/mm/°C (6.7 to 7.1 x 10^{-6} in./in./°F), as shown in Figure 4.13. Extension of the mortar materials with aggregate did not have a substantial effect on this property.

Freeze-Thaw Resistance

None of the repair materials demonstrated outstanding resistance to freeze-thaw deterioration. All durability factors, which are calculated on a scale of 100, were approximately 40 or less (Figure 4.14). None of the materials were tested with river gravel extension because the gravel was known to be non-durable. Five Star® Highway Patch and Set-45® were most resistant to freeze-thaw damage, while Rapid Set® Concrete and Set-45® Hot Weather lasted only 10 and 7 test cycles, respectively (out of 300 possible test cycles).

Length Change in Air and Water

All of the repair materials exhibited linear shrinkage less than 0.1 percent, as shown in Figure 4.15. Five Star® Highway Patch shrunk the most, while Set-45® and Set-45® Hot Weather shrunk the least. Extension of the mortar materials with aggregate did not have a substantial effect on shrinkage.

All of the repair materials exhibited linear expansion less than 0.02 percent, as shown in Figure 4.16. Rapid Set® Concrete experienced the highest linear expansion at 0.016 percent. Set-45® and Set-45® Hot Weather experienced essentially no expansion. Extension of the mortar materials with aggregate did not have a substantial effect on expansion in water.

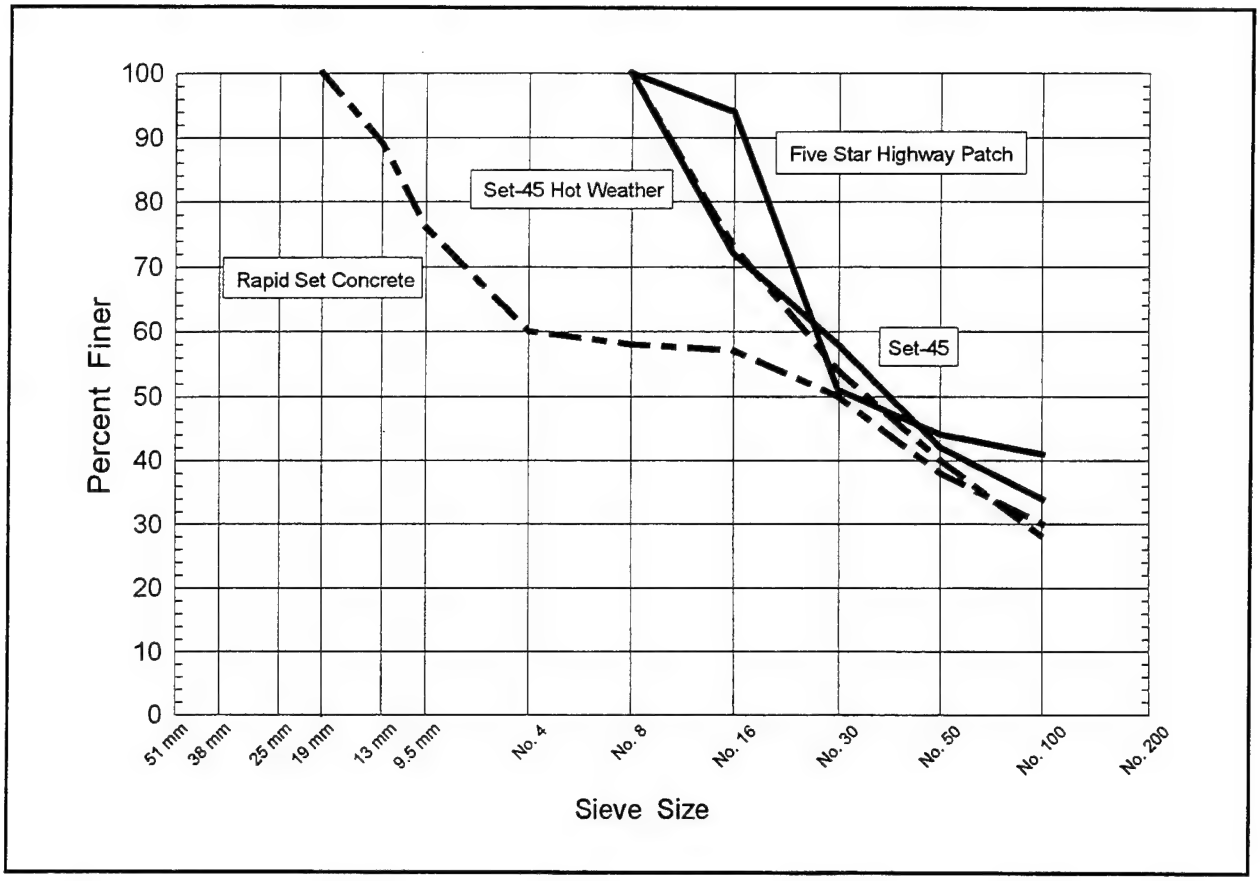

Figure 4.1. Particle size analyses for as-received materials

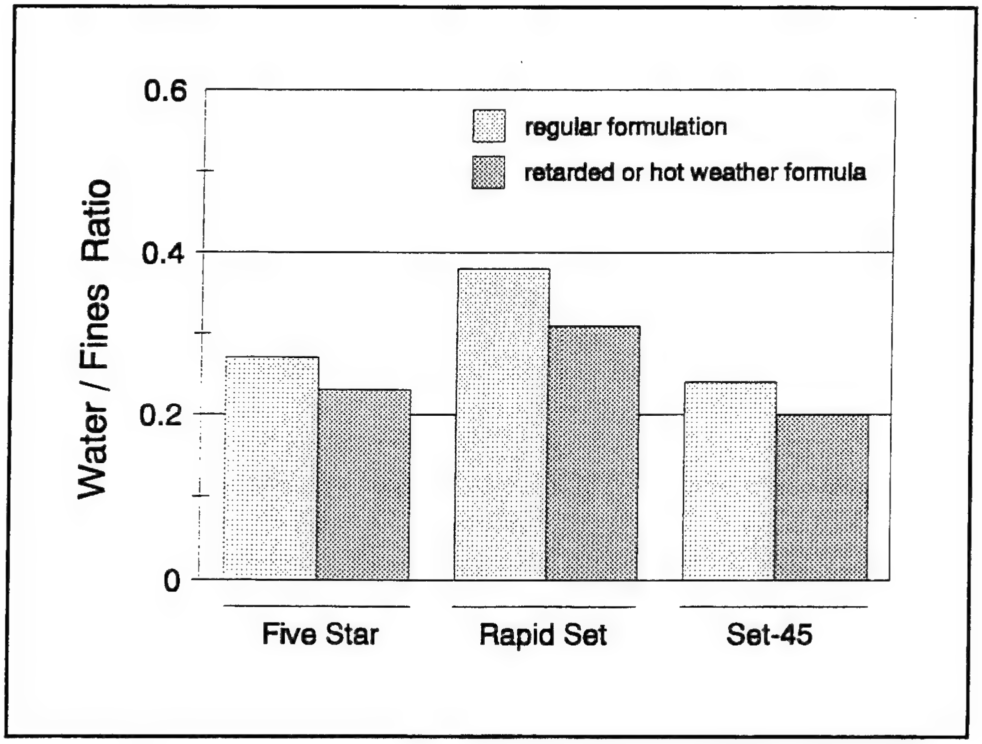

Figure 4.2. Water requirement for normal consistency

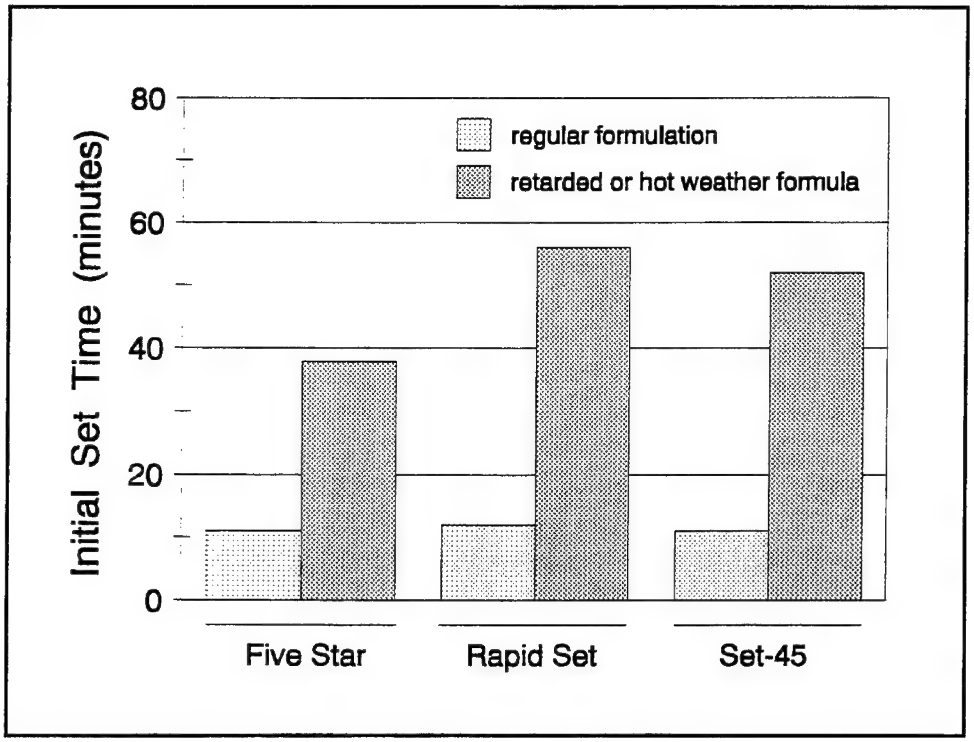

Figure 4.3. Initial set time (Vicat) for -#100 sieve fraction

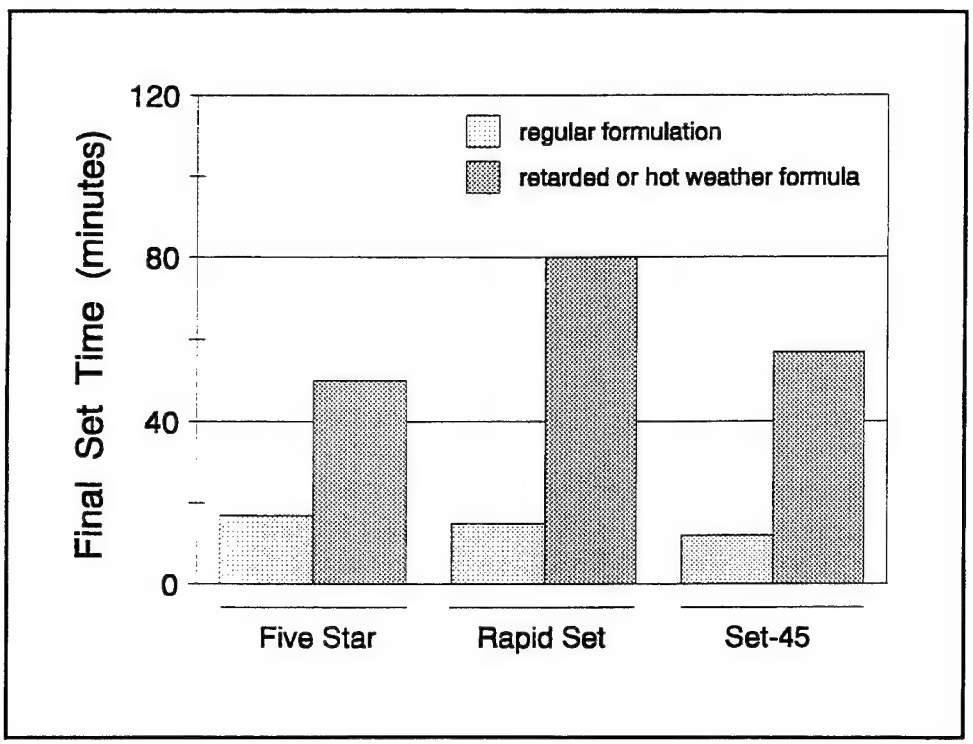

Figure 4.4. Final set time (Vicat) for -#100 sieve fraction

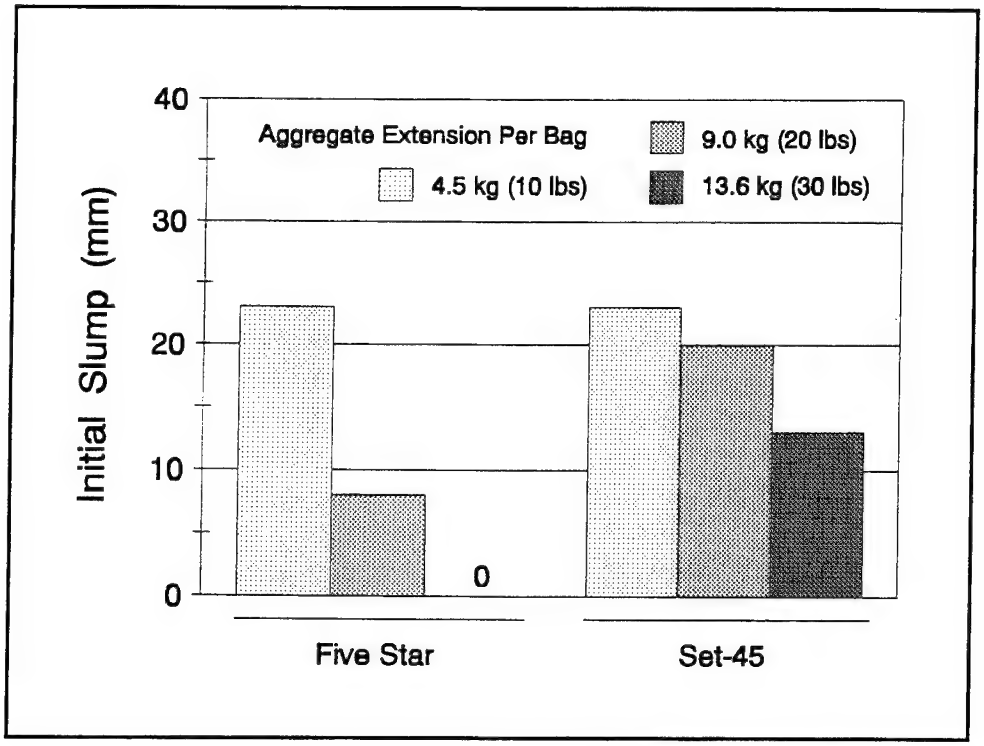

Figure 4.5. Initial slump for mixtures extended with aggregate

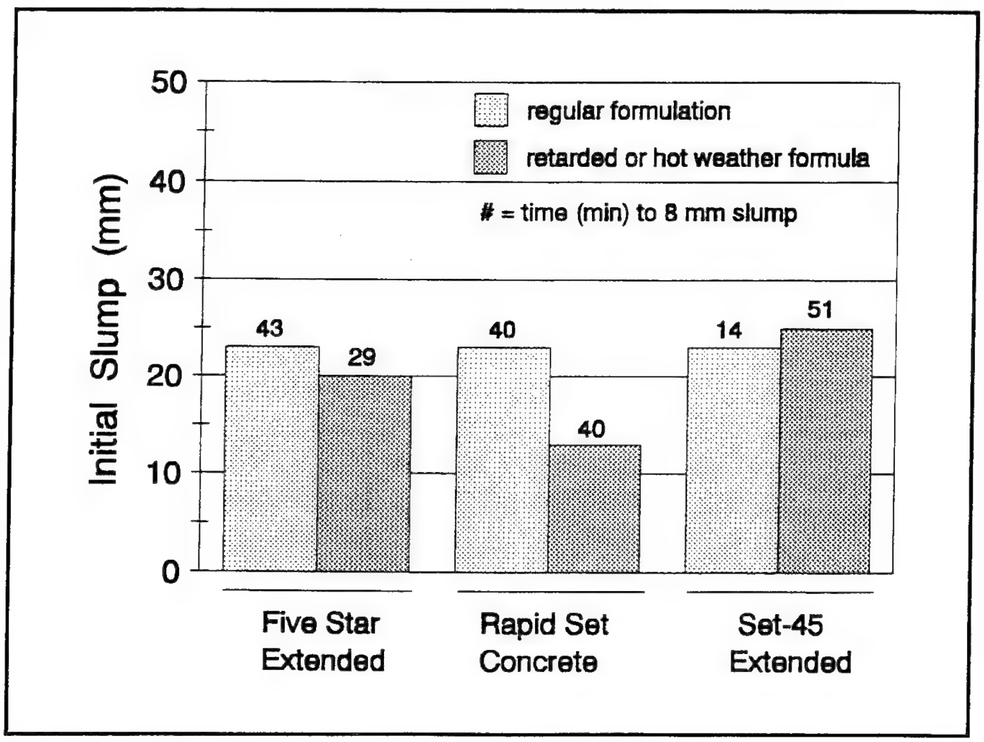

Figure 4.6. Initial slump and rate of slump loss

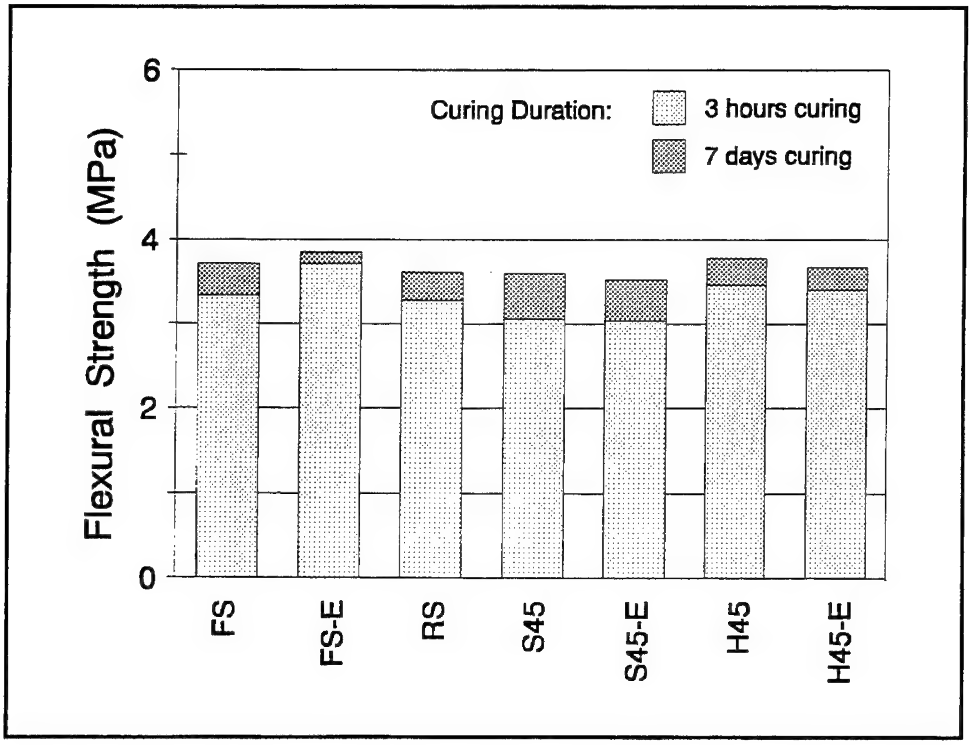

Figure 4.7. Flexural strength for beams cast and cured at 25°C (77°F)

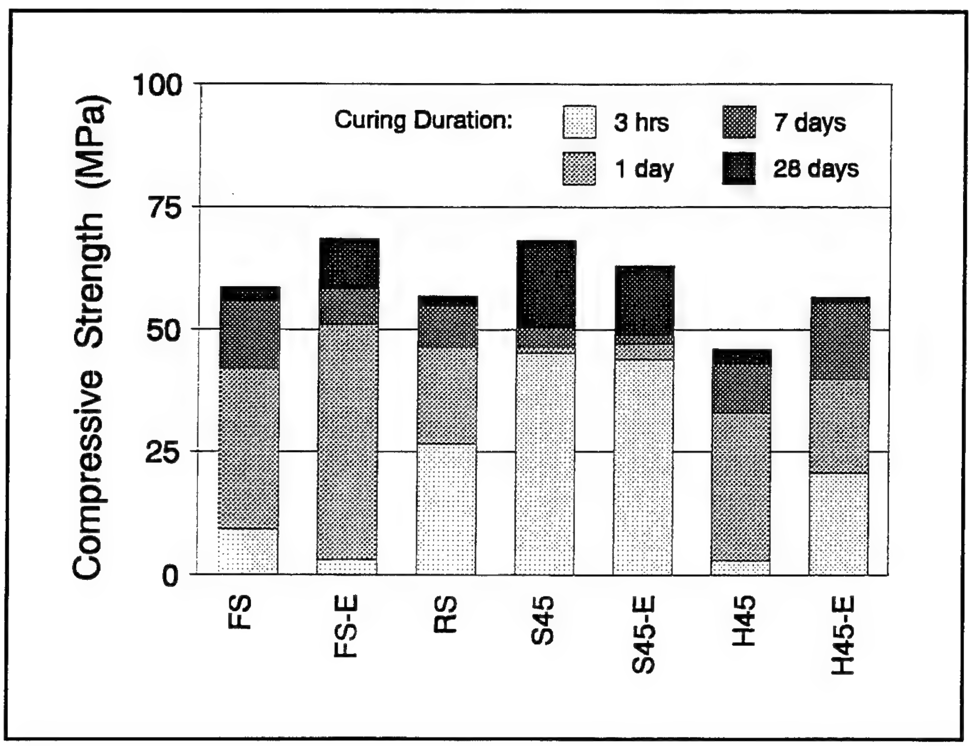

Figure 4.8. Compressive strength for cubes cast and cured at 25°C (77°F)

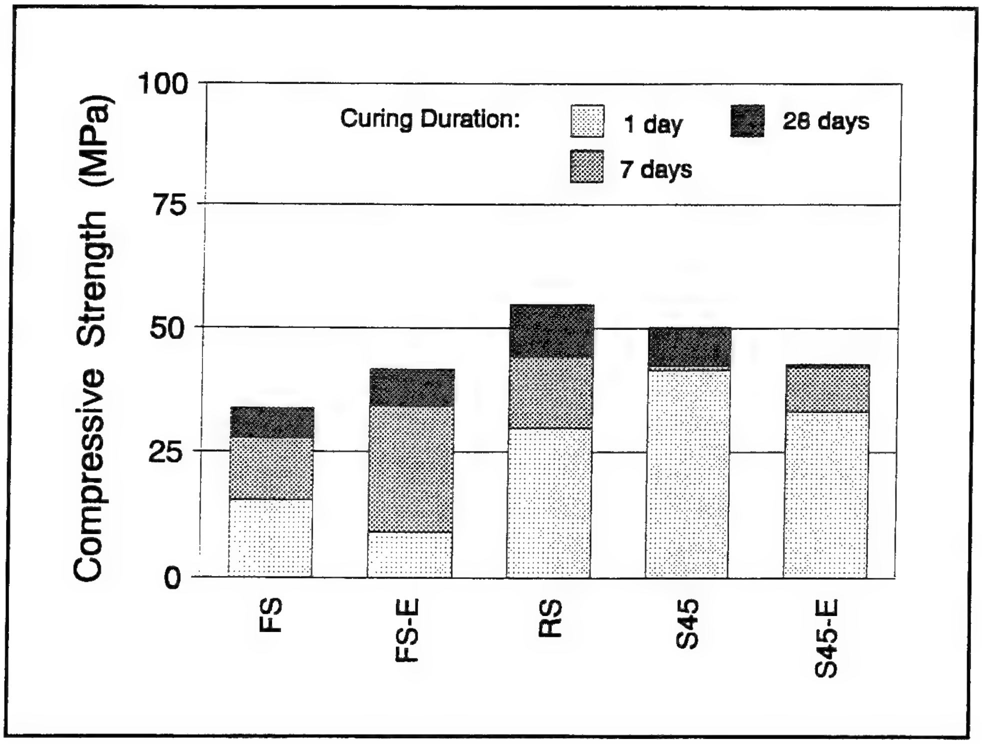

Figure 4.9. Compressive strength for cubes cast and cured at 2°C (35°F)

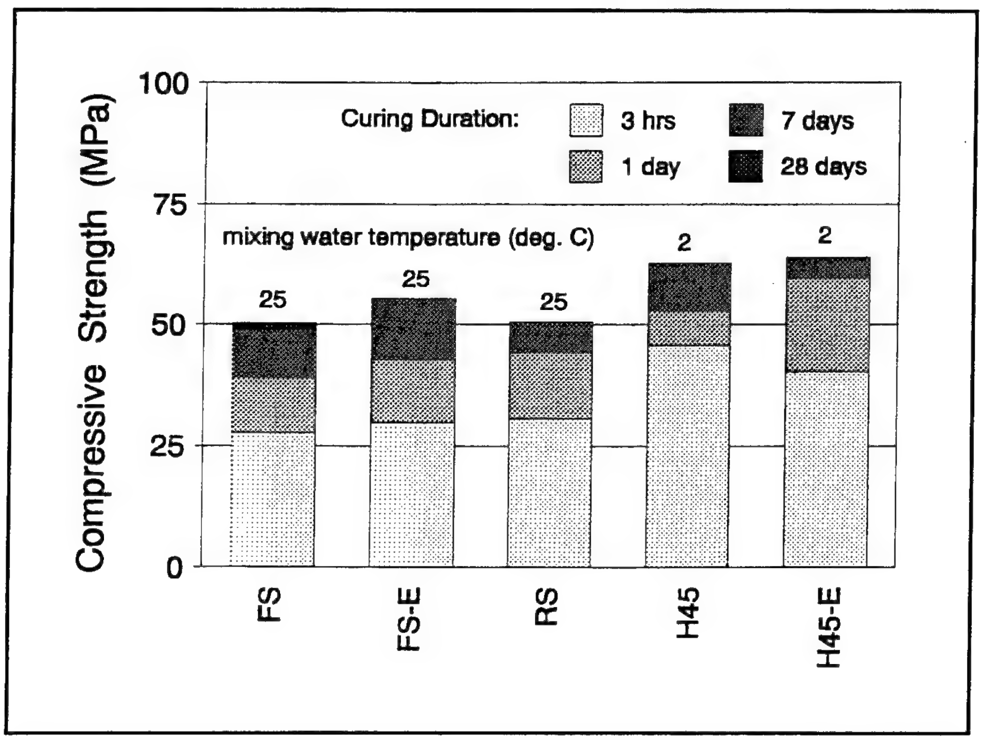

Figure 4.10. Compressive strength for cubes cast and cured at 46°C (115°F)

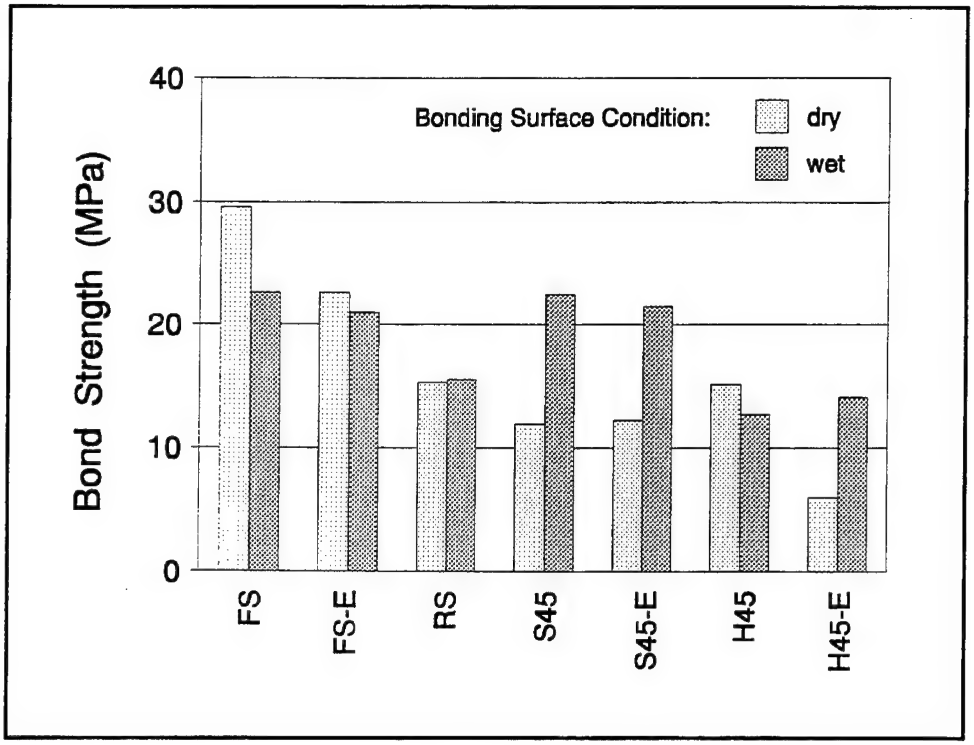

Figure 4.11. Bond strength at 7 days

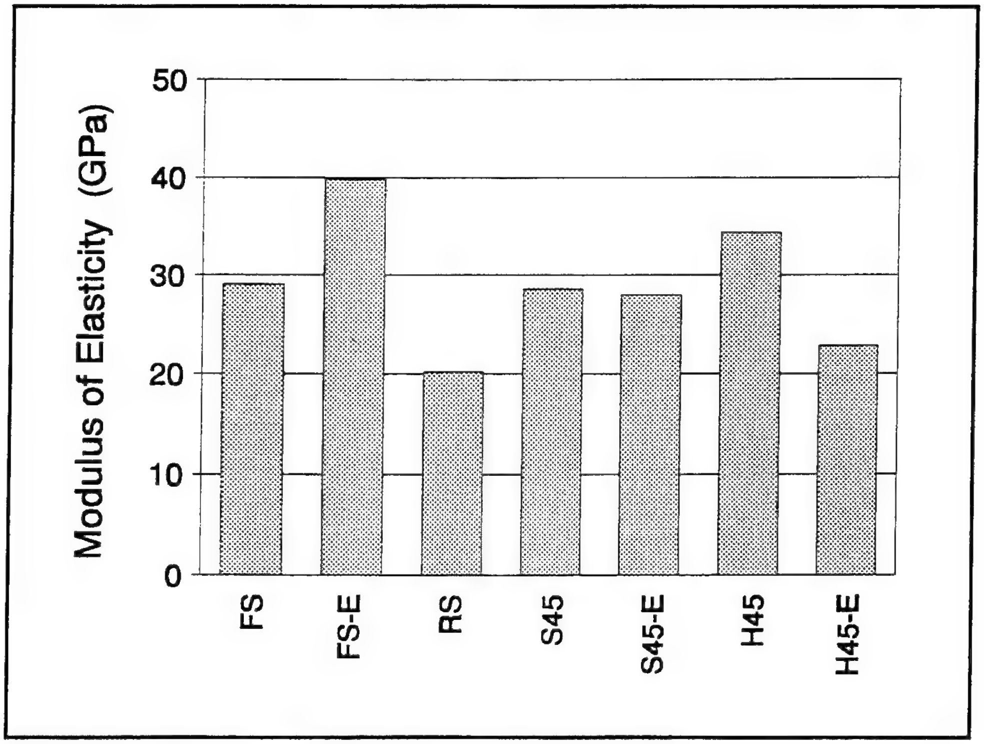

Figure 4.12. Static modulus of elasticity at 7 days

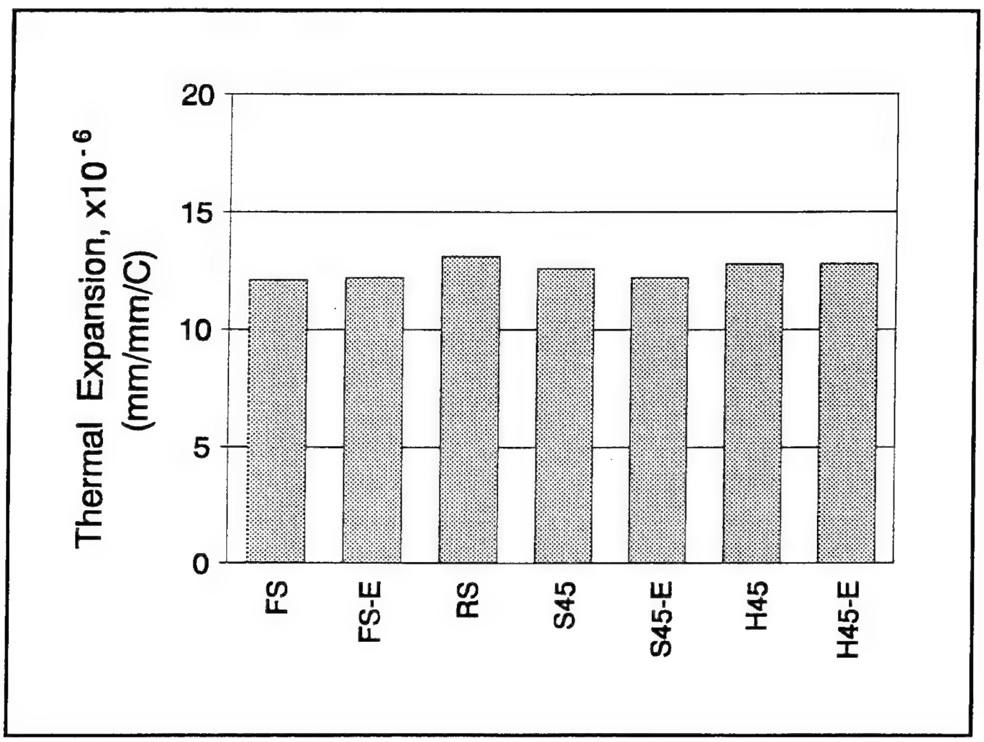

Figure 4.13. Coefficient of thermal expansion

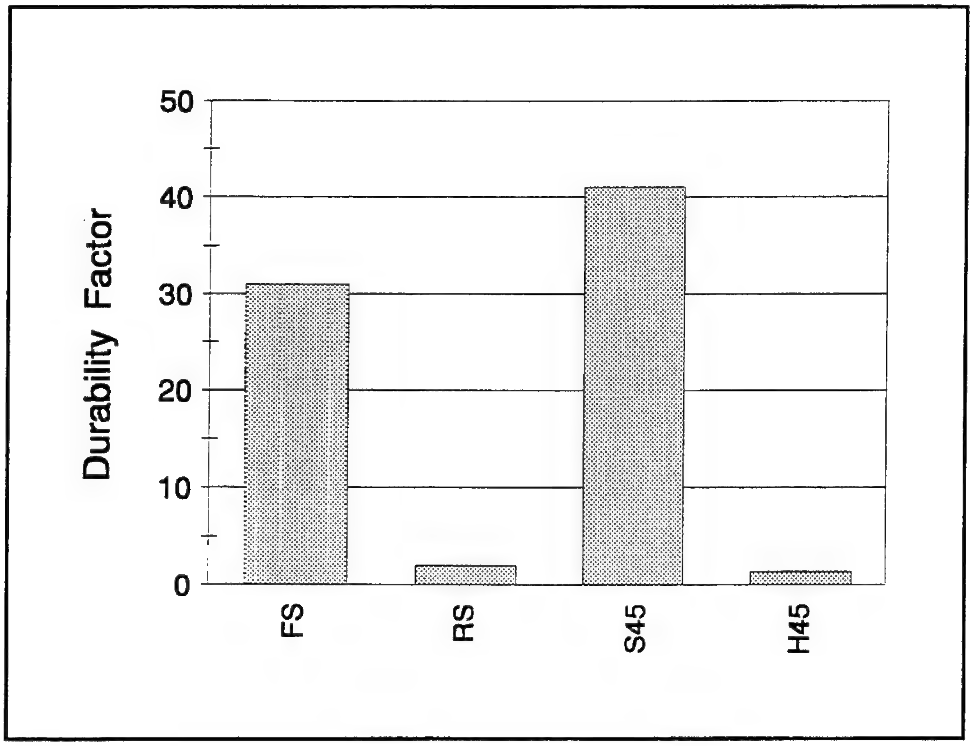

Figure 4.14. Resistance to damage by freeze-thaw cycles

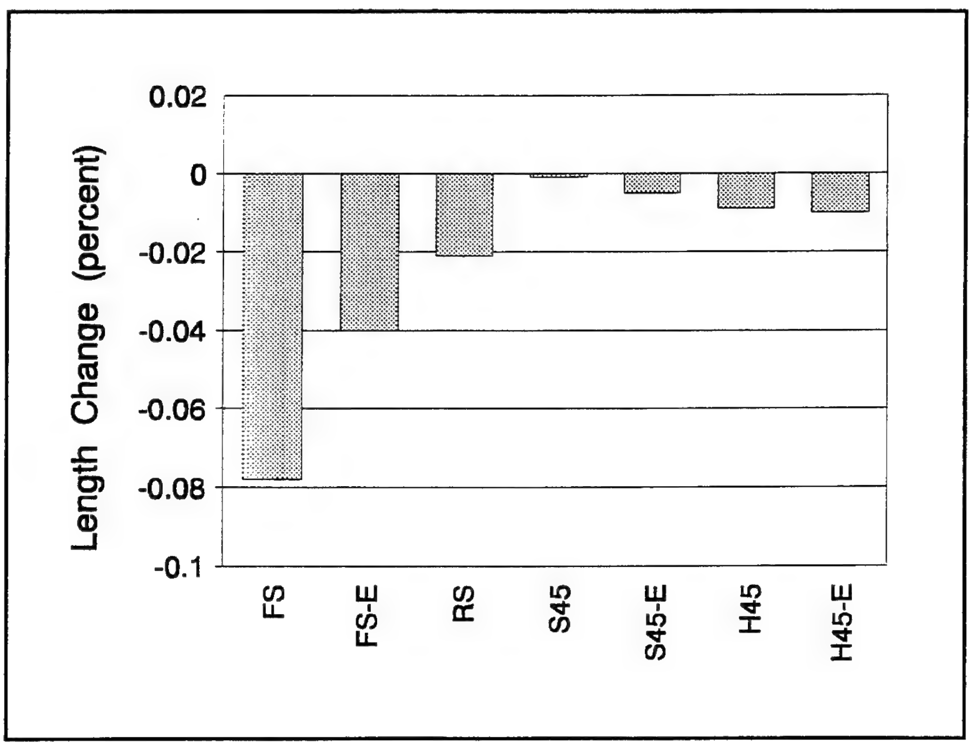

Figure 4.15. Shrinkage caused by drying in air

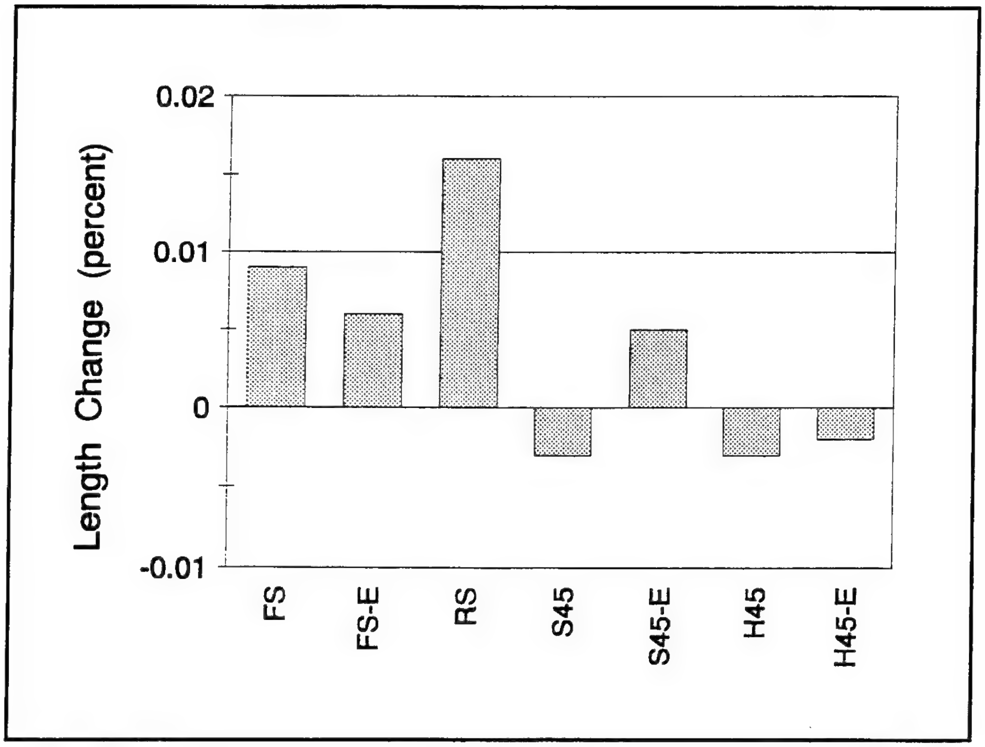

Figure 4.16. Expansion caused by soaking in lime-saturated water

5 Field Evaluation

Each of the repair materials included in this report was used for small spall repairs at Tyndall Air Force Base (AFB), Florida, during the month of September 1995. The spall repairs were executed within Taxiway A, which happened to be closed during this time period, due to additional reconstruction activities. Taxiway A was constructed in 1951 and consists of 250 mm (10 in.) of portland cement concrete.

The prepackaged repair materials and the necessary aggregates for volume extension were shipped to Tyndall AFB, prior to the arrival of Waterways Experiment Station personnel. All the equipment necessary for spall preparation and material placement were provided by the maintenance crew at Tyndall AFB.

Thirteen spalls were selected for repairs. This number permitted the use of four material variations, each at three repair locations. In addition, Fondag Concrete was used for repairing the largest spall because it was a material favored by and available to the maintenance crew at Tyndall AFB.

Preparation of Spalled Areas

The spalled areas were isolated by cutting 50 mm (2 in.) vertically into the concrete surface with a 200-mm (8-in.) diamond-studded saw blade. Cutting was performed far enough away from the spalled concrete surface to ensure that all damaged concrete would be removed for the repair.

Concrete in the spalled areas was broken up with a 40-kg (90-lb) jackhammer. Concrete pieces were then removed by hand. This jackhammer was much heavier than that which is typically recommended for partial-depth repairs [i.e. 14-kg (30-lb)]. However, it was the only hammer available to the maintenance crew at the time. Effort was made to minimize any damage that could be caused to underlying and adjacent concrete by the use of a heavy hammer. The depth of concrete removal was maintained at 50 to 125 mm (2 to 5 in.). Soundings with a metal hammer were performed to ensure that the concrete left in place was intact.

Partial-depth repair surfaces were cleaned with high-pressure water and air in the following sequence: air, water, air. Sand-blasting equipment was not available.

Method of Placement

Spall repair materials were placed in the order shown in Table 5.1. Placements began at 07:00 and were completed at 15:00. Weather was clear and temperatures reached approximately 32°C (90°F) by early afternoon.

Table 5.1
Summary of Joint Spall Repairs at Tyndall AFB, Taxiway A

Spall No.	Spall Location	Material[1]	Aggregate Extension[2]
1	Corner	Set-45®	Y
2	Corner	Set-45®	Y
3	Edge	Set-45®	Y
4	Corner	Rapid Set®	N
5	Corner	Rapid Set®	N
6	Corner	Rapid Set®	N
7	Corner	Five Star®	Y
8	Corner	Five Star®	Y
9	Corner	Five Star®	Y
10	Corner	Five Star®	N
11	Corner	Five Star®	N
12	Two adjacent corners	Five Star®	N
13	Edge	Fondag	N

[1] Master Builders Set-45®, Rapid Set® Concrete, Five Star® Highway Patch, Fondag Concrete.
[2] N = No aggregate added, Y = 13.6 kg (30 lbs) of 9.5-mm (3/8-in.) pea gravel.

These field placements were performed prior to any thorough laboratory evaluation, so information printed on the packages was used to make several decisions. Set-45® was placed first because it was reported to have the shortest working time and it was not recommended for placements at temperatures over 29°C (85°F). Set-45® was extended with aggregate because extension was recommended for patches greater than 25 mm (1 in.) deep. The level of extension used was that which was reported to be the maximum recommended: 13.6 kg (30 lb). Rapid Set Concrete and Fondag concrete were prepackaged with coarse aggregate, so they were not extended. Five Star® Highway Patch was used neat (without aggregates) and extended. The level of extension used was that which was reported to be the maximum allowed: 13.6 kg (30 lb), similar to the Set-45®.

All mixing was executed with a mortar mixer. The sequence with which the materials were added to the mixer followed manufacturer recommendations.

Materials for each individual spall repair were mixed separately. Each mix included at least two bags of material [at least 45 kg (100 lb)] to minimize problems associated with mortar sticking to the walls of the mixer. The mixer was cleaned thoroughly with water prior to changing material type (i.e. every third spall repair). Mixing durations followed manufacturer recommendations, which ranged from 1 min to several minutes.

All existing concrete surfaces to which the repair materials were supposed to bond were moist but without free-standing water. An immersion vibrator was not available at the time of executing the repairs, so all consolidation was performed with hand tools. Curing was performed by immediately covering each patch with a sheet of polyethylene. Repair surfaces were repeatedly uncovered, moistened, and recovered for several hours, with exception for the Set-45® patches. Master Builders recommends that no additional moisture be added to Set-45® during curing.

Field Notes During Placement

In all cases of extending mixtures with the maximum recommended level of aggregate, the resulting mixtures were difficult to consolidate and finish. As a result, the surfaces were rough and over-worked. In addition, consolidation adjacent to the vertical saw-cuts was questionable. Rapid Set® Concrete, non-extended Five Star®, and Fondag were each easy to consolidate and finish.

Prior to placing Fondag in the last patch, an attempt was made to use Set-45®. By this time, the air temperature was above the recommended maximum for this material and the mixing water was probably about 32°C (90°F) because it had been sitting on the back of a truck in a large plastic tank. The Set-45® hardened approximately 2 min after adding water, before it could be placed in the patch area. The Fondag, known to be more amenable to hot placement temperatures, was then used for this last patch. The Fondag provided ample working time under the same conditions.

Performance After One Year

The patches that consisted of Set-45® extended with aggregate appeared to be so poorly consolidated that the maintenance crew decided to remove and replace two of the three patches soon after their installation. The third patch had exposed aggregate after one year of service. The thin layer of over-worked paste had been abraded away by traffic. The bond interfaces, however, appeared to be in good condition. There were no shrinkage cracks and no loss of material.

The Rapid Set® Concrete patches were very noticeable due to their color contrast with the concrete pavement. The Rapid Set® patches were light orange to peach in color, while the rest of the concrete pavement was light to dark

gray. The color contrast was severe enough that it could be distracting to pilots or at least aesthetically displeasing. Each of the Rapid Set® patches cracked. Two of the patches cracked down their middle, while the third had a crack running parallel to and approximately 20 mm away from a bond interface. The patch material at the bond interfaces appeared to have pulled away from the concrete to which it was bonded, leaving cracks about 0.8 mm (0.03 in.) in width. No material had been dislodged from the patch.

The Five Star® that was extended with aggregates performed well in terms of shrinkage. No shrinkage cracks were found and the bond interfaces appeared to be tight and intact. Two of the three patches, however, had some slight chipping at the edges. This was believed to be related to the consolidation problems reported earlier.

When Five Star® was used without aggregates, one of the three patches exhibited shrinkage cracking and the bond interfaces did not seem as tight as when aggregates were used. Slight chipping was also evident at the patch edges for two of the repairs. The smallest of the three patches in this set appeared to have performed the best.

The Fondag repair was tan in color, but it did not stand out as drastically as the Rapid Set® Concrete repairs. This was the largest repair at 1.2 m x 0.4 m (4 ft x 1.25 ft), so it was most susceptible to shrinkage cracking problems. A single crack [1.6 mm (0.06 in.)] had formed down the middle of the patch, transverse to its long dimension. However, the patch appeared to be well-bonded to adjacent concrete.

In general, none of the patches still in place had suffered severe loss of material. Soundings with a metal hammer revealed no severe delaminations within patches. However, in some cases where debonding at patch edges was visually obvious, soundings revealed that the debonding was not just surficial. The most disturbing soundings occurred adjacent to the Fondag repair. This repair extended along a joint to within about 200 mm (8 in.) of an orthogonal joint. The concrete that had been left intact between the patch and the orthogonal joint sounded fractured. This concrete may have been disturbed during spall repair preparation or it may have cracked during the one year of patch service.

6 Summary and Recommendations

This study demonstrated several reasons for the importance of ongoing repair material evaluations:

a. The physical and mechanical properties published by the material manufacturers were not sufficient to evaluate and compare materials properly.

b. Each material included in this study had distinct advantages and disadvantages.

c. Mixture proportioning guidelines printed on the material packages needed adjustments for the particular aggregates and placement temperatures implemented in this study.

Some of these ongoing material evaluations can be performed by research laboratories, but personnel who plan on using the repair materials must also evaluate materials with "trial mixtures." Trial mixtures can be used to ensure that a material has adequate workability, finishability, and resistance to segregation under the conditions of a particular site. Trial mixtures should be produced with the same materials, the same mixture proportions, and under the same climatic conditions as those anticipated for real placements.

The three materials included in this study are summarized below, with emphasis on their advantages and limitations. The three materials included: Five Star Highway Patch, manufactured by Five Star® Products, Inc.; Rapid Set® Concrete, manufactured by CTS Cement Mfg. Co.; and Set-45®, manufactured by Master Builders, Inc. Detailed test results are provided in Appendices B through E. Material fact sheets are provided in Appendix F.

Five Star® Highway Patch

Five Star® Highway Patch is packaged as a dry mortar and costs about $20 per 22.7 kg (50 lb) bag. It contains a modified high-alumina cement, for which a patent is pending, and sand. Five Star® can be extended with up to 4.5 kg (10 lbs) of 4.8 mm to 12.5 mm (1/4 in. to 1/2 in.) river gravel, while

maintaining a slump of 23 mm (9 in.). Mixing, placing and finishing aggregate-extended Five Star® mixes is similar to that for normal concrete operations.

At room temperature [25°C (77°F)], Five Star® provides approximately 45 min of working time. This length of time was not extended at room temperature by adding Five Star® Summerset retarding admixture. Adding Five Star® Summerset admixture to high temperature placements [46°C (115°F)] was effective in providing working times on the order of at least 20 min, as long as the mixing water is cooled to room-temperature.

The ability for Five Star® to gain strength quickly was dependent on its ability to generate heat, which was affected by both specimen size and placement temperature. At room temperature (25°C), beams with volumes of 0.012 m^3 (0.42 ft^3) attained 90 percent of their 7-day flexural strength in 3 hr. At the same temperature, cubes with volumes of 0.0001 m^3 (0.005 ft^3) attained only 5 percent of their 7-day compressive strength in 3 hr. If a repair is larger than about 0.01 m^3, it should be able handle traffic after only 3 hr. If a repair is smaller than 0.01 m^3, additional curing time will be required. As placement temperatures increase above 25°C, necessary curing times will be reduced.

Five Star® bonded well to ordinary concrete under both dry and wet conditions. The modulus of elasticity and coefficient of thermal expansion for Five Star® were on the order of ordinary concrete, so there were no apparent compatibility problems.

Five Star® demonstrated moderate freeze-thaw resistance. Shrinkage during dry curing and expansion during wet curing were minimal in the laboratory. In field placements, aggregate-extended Five Star® mixtures performed very well in terms of shrinkage. The patch/slab interfaces remained "tight" and well-bonded through one year of service.

Rapid Set® Concrete Mix

Rapid Set® Concrete Mix is packaged as a dry concrete and costs about $15 per 27.2 kg (60 lb) bag. It contains 9.5 mm (3/8 in.) aggregate and an hydraulic cement with high chemical contents of alumina and sulfur trioxide. Mixing and placing Rapid Set® Concrete is similar to that for normal concrete operations. Finishing Rapid Set® Concrete is slightly difficult due to its sticky nature. An aesthetic disadvantage of Rapid Set® Concrete is its peach to orange color that makes partial-depth spall repairs stand out against pavements, which are typically light gray to dark gray in color.

At room temperature [25°C (77°F)], Rapid Set® Concrete provides approximately 40 min of working time. This length of time was not extended at room temperature by adding Set Control™ retarding admixture. Adding Set Control™ admixture to high temperature placements [46°C (115°F)] was effective in

providing working times on the order of at least 20 min, as long as the mixing water is cooled to room-temperature.

The ability for Rapid Set® Concrete to gain strength quickly was dependent on its ability to generate heat, but this effect was not as substantial as it was for Five Star® Highway Patch. At room temperature (25°C), beams with volumes of 0.012 m^3 (0.42 ft^3) attained 90 percent of their 7-day flexural strength in 3 hr. At the same temperature, cubes with volumes of 0.0001 m^3 (0.005 ft^3) attained only 50 percent of their 7-day compressive strength in 3 hr. If a repair is larger than about 0.01 m^3, it should be able handle traffic after only 3 hr. If a repair is smaller than 0.01 m^3, additional curing time may be required. As placement temperatures increase above 25°C, necessary curing times will be reduced.

The Rapid Set® Concrete package provides guidelines for mixing water and retarder dosages, as a function of placement temperature. Trial mixtures performed in this study revealed that the high water contents recommended for high-temperature applications produced "soupy" mixtures with low strengths. Trial mixtures also revealed that the low water contents recommended for low-temperature applications did not provide adequate workability. The water content that the manufacturer recommended for room-temperature placements was most suitable for all placement temperatures.

The bond strength of Rapid Set® Concrete was 70 percent as high as the bond strength of aggregate-extended Five Star. The bond strength of Rapid Set® Concrete was not affected substantially by the moisture condition of the substrate concrete. The modulus of elasticity and coefficient of thermal expansion for Rapid Set® Concrete were on the order of ordinary concrete, so there are no apparent compatibility problems.

Rapid Set® Concrete demonstrated poor freeze-thaw resistance. Shrinkage during dry curing and expansion during wet curing were minimal in the laboratory. In field placements, however, Rapid Set® Concrete patches suffered two forms of distress related to shrinkage. Separation at the patch/slab interfaces was easily visible and each of three patches cracked, apparently due to stresses generated by shrinkage.

Set-45®

Set-45® is packaged as a dry mortar and costs about $25 per 22.7 kg (50 lb) bag. It contains a magnesium phosphate cement and sand. Set-45® can be extended with up to 4.5 kg (10 lbs) of 4.8 mm to 12.5 mm (1/4 in. to 1/2 in.) river gravel, while maintaining a slump of 23 mm (9 in.). Mixing, placing and finishing aggregate-extended Set--45® mixes is similar to that for normal concrete operations.

At room temperature [25°C (77°F)], Set-45® provides only 14 min of working time. Set-45® Hot Weather formulation, however, provides about 50 min of working time. The hot weather formulation is more expensive than

the ordinary formulation; it costs about \$45 per 22.7 kg (50 lb) bag. Set-45® Hot Weather formulation can be used for high temperature placements [46°C (115°F)] as long as ice-water is used for mixing.

Set-45® is effective in gaining high-early strength, independent of sample size. At room temperature (25°C), beams with volumes of 0.012 m^3 (0.42 ft^3) attained 85 percent of their 7-day flexural strength in 3 hr. At the same temperature, cubes with volumes of 0.0001 m^3 (0.005 ft^3) attained 90 percent of their 7-day compressive strength in 3 hr. Any spall repair placed at room temperature should be able handle traffic after only 3 hr.

If Set-45® Hot Weather formulation is used at room temperature (25°C), its ability to gain high-early strength is dependent on sample size. beams with volumes of 0.012 m^3 (0.42 ft^3) attained 90 percent of their 7-day flexural strength in 3 hr. Cubes with volumes of 0.0001 m^3 (0.005 ft^3) attained less than 10 percent of their 7-day compressive strength in 3 hr.

Set-45® and Set-45® Hot Weather were particularly sensitive to water content. Water contents that exceeded manufacturer recommendations only slightly (i.e. 10 percent) produced mixtures that were "soupy," susceptible to segregation, and weak.

Set-45® bonded well to ordinary concrete, as long as the ordinary concrete was wet. Under dry conditions, bond strength of Set-45® was reduced by approximately 50 percent. The bond strength of Set-45® Hot Weather formulation was lower and less consistent than that for ordinary Set-45®. The modulus of elasticity and coefficient of thermal expansion for both Set-45® and Set-45® Hot Weather were on the order of ordinary concrete, so there are no apparent compatibility problems.

Set-45® demonstrated moderate freeze-thaw resistance and Set-45® Hot Weather demonstrated poor freeze-thaw resistance. Shrinkage during dry curing and expansion during wet curing were minimal in the laboratory.

The field placements for Set-45® included the maximum recommended amount of aggregate for volume extension [13.6 kg (30 lb)]. The workability for these mixtures was so poor that they could not be consolidated properly. Two patches were removed due to their non-durable appearance. One patch remained in place and suffered severe abrasion, which was most likely caused by overworking the surface during finishing operations.

Recommendations for Material Utilization

The following recommendations for spall repair materials are based on relative comparisons between the materials included in this study. Decisions are based on consideration for workability, strength, compatibility with substrate concrete, and durability.

For room-temperature placements (approximately 25°C), Five Star® Highway Patch extended with 4.5 kg (10 lb) of aggregate is recommended, as long as the repair area can be closed to traffic for 3 to 6 hr. If the repair area needs to be opened to traffic in less than 3 hr, Set-45® extended with 4.5 kg (10 lb) of aggregate is recommended.

For low-temperature placements (approximately 2°C), Set-45® extended with 4.5 kg (10 lb) of aggregate is recommended. The repair area would need to be closed to traffic for 6 to 12 hr. The use of room-temperature mixing water or the use of insulation blankets over patches is encouraged to increase the rate of strength gain by retaining heat generated by hydration.

For high-temperature placements (approximately 35°C), Five Star® Highway Patch extended with 4.5 kg (10 lb) of aggregate and retarded with Summerset® admixture is recommended. The use of chilled, or at least room-temperature mixing water, is encouraged to extend working time. The repair area would need to be closed to traffic for 3 hr.

Recommendations for Future Testing

Workability

Measuring initial concrete slump provides an indication of concrete consistency, which is somewhat related to workability. Measuring the rate of slump loss over time provides an indication of the duration of adequate working time for concrete. These tests are recommended for future material evaluations. It should be noted, however, that any newly-developed methods for evaluating concrete workability should be considered for application. Repair materials are often sticky and viscous; these characteristics detract from both the repeatability and usefulness of slump measurements.

Vicat set times and their associated determination of "normal consistency" water content have little usefulness when comparing repair materials. The set times for all hydraulic cement repair materials will be quick because they generate heat quickly. Since set times are determined for fines alone and slump loss is determined for concrete mixtures, they do not necessarily correlate. Vicat set times and consistency tests are not recommended for future material evaluations.

Strength

Bond strength, flexural strength, and compressive strength are all useful for comparing repair materials and are all recommended for future material evaluations. In order to evaluate material sensitivity to moisture conditions, slant-shear bond strength tests should be performed with both dry and wet substrate concrete. According to ASTM C 882 (ASTM 1995b), these tests are performed with 76 x 152-mm (3 x 6-in.) cylinders. This size should be adequate

for most repair materials that are sold as mortars. If a repair material contains coarse aggregate, however, it is recommended that all particles larger than 9.5 mm (3/8 in.) be removed by sieving the wet concrete. Bond strength should be measured at an early age (e.g. 1 day) and at a later age when the repair material has gained almost all of its strength (e.g. 7 days).

Consideration needs to be given toward specimen size for both flexural and compressive strength tests. Some repair materials are better able to gain strength quickly when they are placed in large, deep sections because they are then able to generate heat. Conservative estimates for early strength can therefore be obtained with small specimens. Specimen sizes should certainly be consistent for proper comparisons between materials. Specimen sizes should represent reasonable volumes of material, relative to volumes used in partial-depth spall repairs. Prism specimens with approximate dimensions 76 x 76 x 280 mm (3 x 3 x 11 in.) are recommended for flexural strength tests. Cylindrical specimens with dimensions 76x152 mm (3x6 in.) are recommended for compressive strength tests.

For hydraulic-cement based repair materials, strength tests at curing durations of 3 hr, 1 day, 7 days, and 28 days should be sufficient. Curing should be in accordance with recommendations printed on the packages. If the package states that moist curing is not required, moist curing will probably not be provided by field personnel.

Strength tests should be performed over the temperature range for which the material will be recommended. Any substantial effects by temperature on workability should also be noted. These data will inform the user as to dependencies on temperature for mixing water requirements and the duration of restricted traffic.

Compatibility

Modulus of elasticity and coefficient of thermal expansion tests are recommended for future material evaluations. These tests should be performed on materials after they have gained nearly all of their strength. For most repair materials, these tests may be performed after 7 days of curing. The method of curing should be consistent with the strength tests.

Durability

The freeze-thaw test, in accordance with ASTM C 666 (ASTM 1995b) Procedure A, is recommended for future material evaluations. This test procedure imposes rapid and severe freeze-thaw cycles, so it provides a conservative evaluation for material durability. In the special case of using a spall repair material in an area subjected to deicing chemicals, the evaluation should include ASTM C 672 (ASTM 1995b), "Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals." In the special case of using a spall repair material in an area subjected to mechanical abrasion, the evaluation

should include an appropriate test, such as ASTM C 1138 (ASTM 1995b), "Abrasion Resistance of Concrete (Underwater Method)."

The shrinkage test for dry conditions, based on ASTM C 157 (ASTM 1995b), is not recommended for future material evaluations. Currently, the standard ASTM specification for "Packaged, Dry, Rapid-Hardening Cementitious Materials for Concrete Repairs," ASTM C 928 (ASTM 1995b), requires a modified version of this shrinkage test. In this procedure, the specimen is demolded after 2-3/4 hr of curing so that an initial length measurement can be made at 3 hr. Problems develop with the shrinkage measurements because the repair material may or may not be hot after 3 hr of curing. Length change measurements for specimens that have cooled will include only drying shrinkage. Length change measurements for specimens that are still hot will include both drying shrinkage and thermal shrinkage. Future shrinkage tests should be based on measurements with either an embedded concrete strain meter (e.g. Carlson gage) or a steel restraining ring (WJE 1995). Both of these tests include the effects of multiple sources of shrinkage: autogenous, thermal, and drying.

The standard ASTM specification for cementitious repair materials, ASTM C 928 (ASTM 1995b), also requires a modified version of ASTM C 157 (ASTM 1995b) to be used for measuring expansion in water. Expansion tests should be modified so that the initial length measurements are obtained after 28 days of curing. The first three days should involve curing in accordance with manufacturer recommendations. The remainder of the curing duration should be at 50 percent relative humidity. After taking the initial measurements at 28 days, the specimens should be soaked in lime-saturated water and monitored for changes in length. This procedure will ensure that the concrete is dry at the commencement of soaking and it will ensure that expansion due to heat of hydration does not affect the initial length measurements.

References

American Society for Testing and Materials (ASTM). (1995a). "Cement; Lime; Gypsum," *Annual Book of ASTM Standards*, Vol. 4.01, Philadelphia, PA.

American Society for Testing and Materials (ASTM). (1995b). "Concrete and Aggregates," *Annual Book of ASTM Standards*, Vol. 4.02, Philadelphia, PA.

Wiss, Janney, Elstner Associates, Inc. (WJE). (1995). "Transverse Cracking in Newly Constructed Bridge Decks," NCHRP Project 12-37, National Cooperative Highway Research Program, Transportation Research Board, National Research Council, Washington, D.C.

Appendix A Technical Information Printed on Packages

This appendix contains technical information that is printed on the repair material packages. The information is copied precisely; information is not paraphrased. The purpose of this appendix is to document the information that is available to field personnel at the time of repair operations.

Five Star® Highway Patch

45 Minute Traffic

Applications

For DOT use, patching concrete bridge decks and highways, runways, industrial floors and concrete walls. High bond to old concrete.

Instructions

This bag contains Five Star® Highway Patch, a patented, cementitious mixture. It is a rapid-setting, high-strength product which is salt, oil, and gas resistant and can be opened to highway traffic in 45 minutes.

Existing concrete surface must be thoroughly cleaned of oil and any other deleterious substances. All unsound or damaged concrete should be removed until only sound, clean concrete is exposed within the perimeter of a two-inch minimum vertical saw cut. All loose material should be removed by brushing, washing, and/or oil-free air jet. The existing concrete to be patched should then be thoroughly saturated with water. Standing water should be removed prior to patching.

Five Star® Highway Patch should be mixed in a mortar mixer. Wet down the mixer before using and drain any excess water. With the mixer running, add the minimum recommended water to the mixer, followed by the Five Star® Highway Patch, and if extending, then the aggregate. For water requirement, see front of bag [shown below]. Mix from 2 to 5 minutes. Add more water only if required. Do not exceed the maximum water. Do not mix more material than can be placed in 10 minutes. Five Star® Highway Patch may be extended with clean, washed, 3/8-in. pea gravel or crushed stone. Do not extend with sand.

Water Requirement		
	Per Bag Quarts of Water	
Mix	Min.	Max.
Neat	2½	3
Maximum Extension[1]	2¾	3

[1] 30 lb of 1/4 in. to 1/2 in. dry gravel.

Five Star® Highway Patch may be troweled or poured into the area to be patched. After leveling, the patch can be broomed, brushed, or troweled to the desired finish. Do not place in lifts.

When using at or near freezing temperatures, Five Star® Highway Patch should be stored in as warm a place as possible. The patched area must be kept above 32°F until Five Star® Highway Patch has set.

Summerset® is recommended for extending the working time of Five Star® Highway Patch in hot weather.

For applications during extreme weather conditions, contact the Engineering and Technical Center of U.S. Highway Products.

As soon as the surface of the patch has hardened, flood with sufficient water to keep the surface wet for at least 30 minutes.

The manufacturer assumes no responsibility if instructions are not followed.

Warning

Cementitious material may cause irritation. Avoid contact with eyes and prolonged contact with skin. In case of contact with eyes, immediately flush with plenty of water for at least 15 min. Call a physician. Wash skin thoroughly after handling. Keep out of reach of children.

Rapid Set® Concrete Mix

Just Add Water

Rapid Set® Concrete Mix (3/8 in. Rock) is a unique dry blend of hydraulic cement, sand and gravel (maximum size 3/8 in.) and other ingredients. No chlorides are added. When mixed with water it produces a quality concrete which gains strengths of 2000 psi in one hour and 3000 psi in three hours at normal temperatures. Rapid Set® Concrete is similar in color to portland cement concrete.

Suggested Uses

The material is ideal for applications where quick strength is required, including the patching of highway pavement, sidewalks and floors. Within one hour after placement, Rapid Set® Concrete is ready for traffic. Barricades are not needed.

Mixing and Placement

A slump of about six inches is used for ease of placement and to assure good bond to adjacent materials. This slump requires about 3 qt (3LT) of clean water, 3 to 5 qt (3 to 5 LT) may be used, per 60 lb bag of Rapid Set® Concrete. A 60 lb bag makes approximately one-half cubic foot of concrete. Due to possible segregation of the dry materials, whole bags should be used.

Rapid Set® Concrete has almost zero shrinkage even when placed at a six inch slump.

Excellent bond is achieved when the adjacent material is either wet or dry. Curing after placement is not required.

Rapid Set® Concrete may be placed at temperatures just above 32°F.

The working time for Rapid Set® Concrete is about 20 minutes. It is important that the concreting operation be organized within this time limitation. After about 20 minutes the concrete will begin to harden and placing and finishing operations will be difficult. The working time may be extended by using cold materials.

In order to achieve an initial setting time of 15 minutes and 3,000 psi in 3 hours, the following instructions should be followed for each 60 lb sack.

Temperature (degrees)	Packets of Retarder	Quarts of Water
50	0	3
60	0	3
70	0	4
80	0	4
90	1	5
100+	1½	5½

Caution

Rapid Set® Concrete Mix contains cementitious materials. Freshly mixed concrete may cause skin irritation. Avoid direct contact where possible and wash exposed skin areas promptly with water. If any cementitious material gets into the eye, rinse immediately and repeatedly with water and get prompt medical attention.

Set-45®

Chemical-Action Concrete for fast, permanent concrete repairs.

These suggestions represent generally accepted procedures for successful installation. They may be followed, modified or rejected by the owner, engineer, contractor or their representative since they, not Master Builders, are responsible for planning and executing procedures appropriate to a specific application.

Applications

- Highway and bridge repair
- Cold weather patching
- Industrial concrete repair
- Open to traffic in 45 minutes

Directions

A sound base is essential for good repairs. Remove all oil, grease, dirt and loose, disintegrated or unsound concrete from the areas to be patched.

Saw cut 1/2 in. (13 mm) deep or more to form the boundaries of each patch. When the repair is adjacent to a joint, new expansion joint material or bond breaker - such as thick polyethylene sheeting or preformed isolation joint material - is required to eliminate damage that may occur if adjacent slabs are bonded together. Featheredge patching is not recommended.

Where the bond between reinforcing steel and concrete is destroyed, remove the concrete to a depth that will provide a minimum of 3/8 in. (9.5 mm) of neat Set-45 or 3/4 in. (19 mm) aggregate extended Set-45 over all cleaned concrete surfaces and around all exposed reinforcing. Remove rust from rebars by brushing, high-pressure waterblasting or sandblasting. Do not use a bonding agent on the steel or the concrete surface.

Flush the area with clean water to remove all dust. Air blast with oil-free, compressed air to remove all water before placing Set-45. After surface dries, an indicator should be used to assure a non-carbonated surface for bonding. Note: Set-45 bonds better to a dry surface.

Have proper measuring containers and tools on the job. Be sure adequate labor is available to handle fast-setting material.

Use a mortar-type mixer for best mixing. For large jobs, the mixer should be capable of mixing up to 500 lb (227 kg) of material. A continuous-type mixer may be used. For small batches, a 1/2 hp electric drill mixer may be used.

Use neat material for patches less than 1 in. (25 mm) in depth or width. Set-45 should not be used for patches less than 1/2 in. (13 mm) deep.

A 50 lb (22.7 kg) bag of Set-45 may be extended by adding up to 30 lb (13.6 kg) of thoroughly washed, dried, uniform-sized, sound, 1/4 to 1/2 in. (6 to 13 mm) round aggregate. When using angular aggregate, reduce the maximum amount added to 25 lb (11.4 kg) to obtain the proper workability. Do not add sand, limestone aggregate fines, fly ash or portland cement. Do not use with calcareous aggregate.

To reduce potential thermal stress, placements over 1 ft (0.3 m) deep require Set-45 Hot Weather formula extended with aggregate, providing adequate depth is available at the sides of the repair area. Place in delayed lifts to reduce thermal heat buildup in mass placements.

Locate the mixing operation close to the repair area. Ten minutes are allowed to mix, place and finish Set-45 in normal temperatures [72°F (22°C)].

Important

Water Content is Critical. Use maximum 4 U.S. pints (1.9 liters) of water per 50 lb (22.7 kg) bag of Set-45.

Do not deviate from the recommended water content or mixing instructions. Always follow this mixing order: (1) Pour clean water into mixer. (2) Add aggregate, if necessary, for deep patches. (If damp aggregate is used, reduce the water content accordingly.) (3) Add Set-45. Mix approximately 1 to 1-1/2 minutes. This sequence is important in that it will produce a consistent mix and reduce mixing time.

Only mix quantities that can be placed in 10 minutes or less.

A 50 lb (22.7 kg) bag of Set-45 mixed with the required amount of water produces a volume of approximately 0.39 ft^3 (0.011 m^3). When extended with 60 percent aggregate [30 lb (13.6 kg) per bag], the yield will approach 0.58 ft^3 (0.016 m^3).

Immediately place the properly mixed Set-45 into the prepared area from one side to the other. As the job proceeds, work the material firmly into the bottom and sides of the patch to assure good bond. A bonding agent is not necessary. Level the Set-45 and screed to the elevation of the existing concrete. Seal the edges and all saw cuts with light floating. Minimal finishing is required. (Set-45 finishes more easily with a wood or magnesium float.) Do not retemper the material. Clean tools and mixer frequently with water to prevent buildup. The setting time of Set-45 depends on the temperature of both the mix and the prepared concrete area.

Cold Temperatures: [below 40°F (4°C)]. Heat the concrete surface until it is warm to the touch. Use warm Set-45 and warm water [90°F (32°C)] to increase the rate of hardening. Keeping the Set-45 patch warm by tenting or insulating will aid in obtaining more rapid strength development in cold weather. Do not use antifreeze or accelerators. At an as-mixed temperature of 40°F (4°C), early strength development will be reduced. Set-45 will not freeze at temperatures above 20°F (-7°C).

Hot Temperatures: [85°F to 100°F (29°C to 38°C)]. Set-45 Hot Weather formula with maximum aggregate extension is recommended. Keep Set-45 cool. Mixing with ice water is recommended to extend the working time.

Caution: Placing Set-45 on a hot concrete surface may affect the bond. When the surface is hot, reduce the slab temperature by wetting the area. Remove all standing water before applying Set-45.

Set-45 should air dry for proper cure. Do not wet cure. Plastic sheeting or curing compounds may be used to give the surface early protection from rain, snow, water, wind, etc. At normal ambient temperatures, Set-45 will take rubber tire traffic approximately 45 minutes after placement.

Supplemental

When mixing or placing Set-45 in a closed area, provide adequate ventilation. Store in a dry place. Water or high humidity will affect the shelf life of this product. When used in contact with galvanized steel or aluminum, consult your local Master Builders dealer or sales representative.

Risk

- eye irritant
- skin irritant
- lung irritant
- may cause delayed lung injury

Precaution

- avoid contact with eyes
- wear suitable protective eyewear
- wear suitable gloves
- wear suitable protective clothing
- do not breathe dust
- in case of insufficient ventilation, wear suitable respiratory equipment
- wash soiled clothing before reuse

First Aid

- wash exposed skin with soap and water
- flush eyes with large quantities of water
- if breathing is difficult, move person to fresh air

Waste Disposal Method

This product when discarded or disposed of is not listed as a hazardous waste in federal regulations. Dispose in a landfill in accordance with local regulations.

Set-45® Hot Weather

Chemical-Action Concrete for fast, permanent concrete repairs.

These suggestions represent generally accepted procedures for successful installation. They may be followed, modified or rejected by the owner, engineer, contractor or their representative since they, not Master Builders, are responsible for planning and executing procedures appropriate to a specific application.

Applications

- Highway and bridge repair
- Industrial concrete repair
- Open to traffic in 45 minutes

Directions

A sound base is essential for good repairs. Remove all oil, grease, dirt and loose, disintegrated or unsound concrete from the areas to be patched.

Saw cut 1/2 in. (13 mm) deep or more to form the boundaries of each patch. When the repair is adjacent to a joint, new expansion joint material or bond breaker - such as thick polyethylene sheeting or preformed isolation joint material - is required to eliminate damage that may occur if adjacent slabs are bonded together. Featheredge patching is not recommended.

Where the bond between reinforcing steel and concrete is destroyed, remove the concrete to a depth that will provide a minimum of 3/8 in. (9.5 mm) of neat Set-45 or 3/4 in. (19 mm) aggregate extended Set-45 over all cleaned concrete surfaces and around all exposed reinforcing. Remove rust from rebars by brushing, high-pressure waterblasting or sandblasting. Do not use a bonding agent no the steel or the concrete surface.

Flush the area with clean water to remove all dust. Air blast with oil-free, compressed air to remove all water before placing Set-45. After surface dries, an indicator should be used to assure a non-carbonated surface for bonding. Note: Set-45 bonds better to a dry surface.

Have proper measuring containers and tools on the job. Be sure adequate labor is available to handle fast-setting material.

Use a mortar-type mixer for best mixing. For large jobs, the mixer should be capable of mixing up to 500 lb (227 kg) of material. A continuous-type mixer may be used. For small batches, a 1/2 hp electric drill mixer may be used.

Use neat material for patches less than 1 in. (25 mm) in depth or width. Set-45 Hot Weather formula should not be used for patches less than 1/2 in. (13 mm) deep.

A 50 lb (22.7 kg) bag of Set-45 Hot Weather formula may be extended by adding up to 30 lb (13.6 kg) of thoroughly washed, dried, uniform-sized, sound, 1/4 to 1/2 in. (6 to 13 mm) round aggregate. When using angular aggregate, reduce the maximum amount added to 25 lb (11.4 kg) to obtain the proper workability. Do not add sand, limestone aggregate fines, fly ash or portland cement. Do not use with calcareous aggregate.

To reduce potential thermal stress, placements over 1 ft (0.3 m) deep, Set-45 Hot Weather must be extended with aggregate. Place in delayed lifts to reduce thermal heat buildup in mass placements.

Locate the mixing operation close to the repair area. Ten minutes are allowed to mix, place and finish Set-45 Hot Weather formula in high temperatures [85°F to 100°F (29°C to 38°C)]. Longer mixing and placing times occur when using Hot Weather formula in cooler temperatures.

Important

Water Content is Critical. Use 3.25 to 3.75 U.S. pints (1.5 to 1.8 liters) of water per 50 lb (22.7 kg) bag of Set-45 Hot Weather.

Do not deviate from the recommended water content or mixing instructions. Always follow this mixing order: (1) Pour clean water into mixer. (2) Add aggregate, if necessary, for deep patches. (If damp aggregate is used, reduce the water content accordingly.) (3) Add Set-45 Hot Weather. Mix approximately 1 to 1-1/2 minutes. This sequence is important in that it will produce a consistent mix and reduce mixing time.

Only mix quantities that can be placed in 10 minutes or less.

A 50 lb (22.7 kg) bag of Set-45 Hot Weather formula mixed with the required amount of water produces a volume of approximately 0.39 ft^3 (0.011 m^3). When extended with 60 percent aggregate [30 lb (13.6 kg) per bag], the yield will approach 0.58 ft^3 (0.016 m^3).

Immediately place the properly mixed Set-45 Hot Weather formula into the prepared area from one side to the other. As the job proceeds, work the material firmly into the bottom and sides of the patch to assure good bond. A bonding agent is not necessary. Level the Set-45 and screed to the elevation of the existing concrete. Seal the edges and all saw cuts with light floating. Minimal finishing is required. (Set-45 finishes more easily with a wood or magnesium float.) Do not retemper the material. Clean tools and mixer frequently with water to prevent buildup. The setting time of Set-45 Hot Weather formula depends on the temperature of both the mix and the prepared concrete area.

Hot Temperatures: [85°F to 100°F (29°C to 38°C)]. Keep Set-45 Hot Weather formula cool. Mixing with ice water is recommended to extend the working time.

Caution: Placing Set-45 on a hot concrete surface may affect the bond. When the surface is hot, reduce the slab temperature by wetting the area. Remove all standing water before applying Set-45.

Normal Temperatures: [60°F to 85°F (16°C to 29°C)]. Set-45 Hot Weather formula may be used in normal temperatures when a delayed setting time is required.

Cold Temperatures: Do not use this product at temperatures below 60°F (16°C) unless longer working time is required and lower early strengths are not a problem. Regular Set-45 is recommended for cold weather concrete repair.

Set-45 Hot Weather formula should air dry for proper cure. Do not wet cure. Plastic sheeting or curing compounds may be used to give the surface early protection from rain, snow, water, wind, etc. At high [85°F to 100°F (29°C to 38°C)] ambient temperatures, Set-45 Hot Weather formula will take rubber tire traffic approximately 45 minutes after placement.

Supplemental

When mixing or placing Set-45 in a closed area, provide adequate ventilation. Store in a dry place. Water or high humidity will affect the shelf life of this product. When used in contact with galvanized steel or aluminum, consult your local Master Builders dealer or sales representative.

Risk

- eye irritant
- skin irritant
- lung irritant
- may cause delayed lung injury

Precaution

- avoid contact with eyes
- wear suitable protective eyewear
- wear suitable gloves
- wear suitable protective clothing
- do not breathe dust
- in case of insufficient ventilation, wear suitable respiratory equipment
- wash soiled clothing before reuse

First Aid

- wash exposed skin with soap and water
- flush eyes with large quantities of water
- if breathing is difficult, move person to fresh air

Waste Disposal Method

This product when discarded or disposed of is not listed as a hazardous waste in federal regulations. Dispose in a landfill in accordance with local regulations.

Fondag

2 to 2.5 hours Workability (at 68°F / 20°C)

Add Only 1/2 U.S. Gallon of Water per 50 lb Bag

General Description

Fondag concrete is a ready-to-use, high-strength, durable concrete. Its special characteristics are achieved using synthetic, hard, dense, non-porous aggregates which develop a very strong chemical bond with the cement. Both aggregates and cement, manufactured by Lafarge Calcium Aluminates, allow Fondag concrete to withstand the toughest conditions demanded by heavy industry.

- Thermal cycling temperatures/high temperatures: -395°F to +2100°F (-184°C to +1150°C).

- Erosion/heavy abrasion: 7 to 10 times more resistant then 5,000 psi portland concrete.

- Mechanical shock.

- Corrosion resistance: diluted acid pH 3.5 to pH 11, H_2S Biogenic corrosion pH 2.

- High early strength:

8,000 psi	(55 MPa)	1 day
9,000 psi	(62 MPa)	7 days
11,000 psi	(76 MPa)	28 days

[(6" x 12" cylinders - 68°F (20°C) moist curing]
Note: These values obtained in controlled laboratory environment. Values may vary slightly in the field.

- Cold weather applications: placeable at curing temperatures as low as 0°F (-18°C) provided the fresh concrete is prevented from freezing until heat evolution begins.

- Ease of use: add potable water only (0.5 to 0.55 U.S. gallons of water 50-lb bag).

Where to Use Fondag Concrete

Fondag concrete can be used for industrial floors or where sever conditions exist which ordinary concretes cannot withstand (interior, exterior, underwater, etc.). Some examples are:

- steel/iron ferrous industry
- aluminum industry
- energy production
- fire training centers
- freezer rooms
- liquid gas industry
- cement industry
- dams
- sewers
- slaughter house floors

Limitations

Fondag concrete (1/2 in. x down) must by used at a depth of 4-6 in. to withstand the toughest environments. Sub-base must be mechanically strong enough to support a Fondag slab. Fondag concrete must be used in the range defined in the general description paragraph. A design engineer should be consulted for advice on concrete reinforcement requirements.

Never add portland cement, other aggregates, or admixtures to Fondag. In certain applications, the addition of metallic and/or non-metallic reinforcing fibers may be desired. For technical assistance, contact Lafarge Calcium Aluminates at 1-800-524-8436 or (804) 543-8832.

Installation

Additional information is available in the "Fondag Installation Guide" and should be reviewed by both designer and installer at the onset of any project. Key points are:

- sub-base must be rough, pre-soaked to saturation, free from surface latency and strong enough to support the Fondag slab

- vibrate the concrete

- generally joints must be spaced 6 ft x 6 ft (e.g. checkerboard, saw cutting or pre-placed strips).

Mixing Procedure for a 50-lb Bag

Always use the 50-lb bag in its entirety. Do not use in parts, segregation may occur.

- Prepare 0.5 to 0.55 U.S. gallons of fresh potable water.
- Use clean tools (no portland buildup).
- Initially, add 80 percent of the water to mixer.
- Add the 50-lb bag (always use a full bag).
- Mix for one minute or until mix is completely "wet."
- Add the remaining water to get the desired consistency (not to exceed 0.55 U.S. gallons of water).
- Mix for three minutes.

Curing

To avoid quick moisture loss at the surface of the concrete, use liquid membrane curing products, plastic sheeting, or waters as soon as the surface begins to harden or heat generation is noticed and the surface begins to turn dry (no fingerprints can be left). At 68°F, this occurs about one and a half hours after batching. Curing must be maintained during the first three hours after placement.

Caution

May cause skin or eye injury. Contains cement. Avoid contact with skin when possible. Wash exposed skin areas promptly with water. In the event of eye contact, rinse immediately and repeatedly with water and get prompt medical attention if irritation persists. Do not take internally. Keep out of reach of children.

Shelf-Life

Fondag has a shelf-life of six to eight months in a low moisture environment. After one year, a brief inspection should be conducted prior to use. Contact Lafarge for more details.

Warranty

Manufacturers warranty is limited to replacement of defective merchandise.

Appendix B
Workability Characteristics

Table B1
Water Contents for Normal Consistency

Material	Water Content, ml	Water/Fines Ratio
Five Star	175	0.27
Five Star + Retarder[1]	150	0.23
Rapid Set	250	0.38
Rapid Set + Retarder[2]	200	0.31
Set-45	155	0.24
Set-45 Hot Weather[3]	130	0.20

[1] 3 tubes, 44 ml per 23-kg bag (1.5 fl oz per 50-lb bag).
[2] 1.5 packets, 51 gm per 27-kg bag (1.8 oz per 60-lb bag).
[3] Manufactured with a retarder.

Table B2
Set Times

Material	Initial Set (minutes)	Final Set (minutes)
Five Star	11	17
Five Star + Retarder[1]	38	50
Rapid Set	12	15
Rapid Set + Retarder[2]	56	80
Set-45	11	12
Set-45 Hot Weather[3]	52	57

[1] 3 tubes, 44 ml per 23-kg bag (1.5 fl oz per 50-lb bag).
[2] 1.5 packets, 51 gm per 27-kg bag (1.8 oz per 60-lb bag).
[3] Manufactured with a retarder.

Table B3
Slump for Five Star Mixtures with Various Amounts of Aggregate

4.5 kg (10 lb) Aggregate		9.1 kg (20 lb) Aggregate		13.6 kg (30 lb) Aggregate	
Time, min	Slump, mm (in.)	Time, min	Slump, mm (in.)	Time, min	Slump, mm (in.)
5	230 (9)	4	75 (3)	4	0
14	230 (9)	7	75 (3)		
22	215 (8.5)				
32	190 (7.5)				
43	75 (3)				
53	65 (2.5)				
66	50 (2)				

Table B4
Slump for Set-45 Mixtures with Various Amounts of Aggregate

4.5 kg (10 lb) Aggregate		9.1 kg (20 lb) Aggregate		13.6 kg (30 lb) Aggregate	
Time, min	Slump, mm (in.)	Time, min	Slump, mm (in.)	Time, min	Slump, mm (in.)
4	230 (9)	4	205 (8)	5	125 (5)
7	230 (9)	7	205 (8)	8	125 (5)
11	230 (9)	9	205 (8)	13	0
13	205 (8)	13	180 (7)		
14	0	14	0		

Table B5
Slump for Five Star Mixtures with 10 lb (4.5 kg) of Aggregate, Non-Retarded and Retarded

No Retarder		With Retarder[1]	
Time, min	Slump, mm (in.)	Time, min	Slump, mm (in.)
5	230 (9)	6	205 (8)
14	230 (9)	18	115 (4.5)
22	215 (8.5)	29	75 (3)
32	190 (7.5)	40	50 (2)
43	75 (3)	47	40 (1.5)
53	65 (2.5)		
66	50 (2)		

[1] 3 tubes, 44 ml per 23-kg bag (1.5 fl oz per 50-lb bag).

Table B6
Slump for Rapid Set Mixtures, Non-Retarded and Retarded

No Retarder		With Retarder[1]	
Time, min	Slump, mm (in.)	Time, min	Slump, mm (in.)
6	230 (9)	6	125 (5)
17	150 (6)	19	100 (4)
29	90 (3.5)	29	100 (4)
40	75 (3)	40	75 (3)
51	40 (1.5)	51	65 (2.5)
		64	50 (2)
		77	40 (1.5)

[1] 1.5 packets, 51 gm per 27-kg bag (1.8 oz per 60-lb bag)

Table B7
Slump for Set-45 Mixtures with 4.5 kg (10 lb) of Aggregate, Non-Retarded and Retarded

No Retarder		Hot Weather Formulation[1]	
Time, min	Slump, mm (in.)	Time, min	Slump, mm (in.)
4	230 (9)	6	255 (10)
7	230 (9)	12	255 (10)
11	230 (9)	18	255 (10)
13	205 (8)	24	255 (10)
14	0	29	255 (10)
		34	255 (10)
		42	230 (9)
		48	265 (6.5)
		51	0

[1] Retarder added by the manufacturer.

Appendix C
Strength Properties

Table C1
Flexural Strengths[1] for Concrete Cast and Cured at 25°C (77°F)

Material	Curing Time	Sample 1	Sample 2	Sample 3	Avg.
Five Star	3 hours	3.31	3.31	3.37	3.33 (485)
	7 days	3.81	3.61		3.71 (540)
Five Star Extended	3 hours	3.46	4.06	4.02	3.85 (560)
	7 days	4.05	3.56	3.53	3.71 (540)
Rapid Set	3 hours	3.30	3.25		3.27 (475)
	7 days	3.34	3.82	3.66	3.61 (525)
Set-45	3 hours	2.97	3.13		3.05 (440)
	7 days	3.42	3.76		3.59 (520)
Set-45 Extended	3 hours	2.96	3.06	3.09	3.03 (440)
	7 days	3.66	3.37		3.52 (510)
Set-45 Hot Weather	3 hours	3.34	3.48	3.56	3.46 (500)
	7 days	3.83	3.63	3.87	3.78 (550)
Set-45 Hot Weather Extended	3 hours	3.30	3.30	3.59	3.40 (495)
	7 days	3.76	3.52	3.72	3.67 (530)

[1] 150x150x510-mm (6x6x20-in.) beams; units of strength are MPa (psi).

Table C2
Compressive Strength[1] for Five Star Materials Cast and Cured at 25°C (77°F)

Curing Time (hrs)	Sample 1	Sample 2	Sample 3	Sample 4	Avg.
As-Received					
3	5.5				5.5 (790)
3.25	7.7				7.7 (1110)
3.5	9.2				9.2 (1340)
3.75	17.6				17.6 (2550)
24	42.3	40.3	43.6	42.0	42.0 (6100)
168	53.8	58.6	54.7		55.7 (8080)
672	56.3	55.3	59.3	63.5	58.6 (8500)
Extended with 4.5 kg (10 lb) of River Gravel					
3	2.01				2.01 (290)
3.25	2.74				2.74 (395)
3.5	4.50				4.50 (650)
3.75	7.08				7.08 (1030)
24	48.8	51.0	52.9	51.1	51.0 (7390)
168	53.3	62.9	58.4		58.2 (8440)
672	65.2	70.6	69.6		68.5 (9930)

[1] 2-in. (51-mm) cubes; units of strength are MPa (psi).

Table C3
Compressive Strength[1] for Rapid Set Concrete Cast and Cured at 25°C (77°F)

Curing Time (hrs)	Sample 1	Sample 2	Sample 3	Sample 4	Avg.
3.00	26.0				26.0 (3770)
3.08	27.3				27.3 (3960)
3.17	27.2				27.2 (3940)
3.25	28.3				28.3 (4100)
24	45.9	45.8	45.9	47.9	46.4 (6730)
168	58.2	56.1	53.6	51.3	54.8 (7950)
672	58.4	56.8	55.6	59.9	56.9 (8260)

[1] 51-mm (2-in.) cubes; units of strength are MPa (psi).

Table C4
Compressive Strength[1] for Set-45 Materials Cast and Cured at 25°C (77°F)

Curing Time (hrs)	Sample 1	Sample 2	Sample 3	Sample 4	Avg.
As-Received					
3	45.6	44.1	44.3	46.7	45.2 (6550)
24	44.5	49.9	45.2	46.0	46.4 (6730)
168	51.3	51.6	50.1	48.9	50.5 (7320)
672	73.1	71.6	62.5	65.1	68.1 (9870)
Extended with 4.5 kg (10 lb) of River Gravel					
3	43.4	41.6	45.5	45.3	43.9 (6370)
24	48.4	48.0	44.9	46.6	47.0 (6820)
168	51.7	49.4	51.3	43.5	49.0 (7100)
672	63.9	66.0	59.3		63.1 (9150)

[1] 51-mm (2-in.) cubes; units of strength are MPa (psi).

Table C5
Compressive Strength[1] for Set-45 Hot Weather Materials Cast and Cured at 25°C (77°F)

Curing Time (hrs)	Sample 1	Sample 2	Sample 3	Sample 4	Avg.
As-Received					
2.97	2.63				2.63 (380)
3.03	2.94				2.94 (425)
3.12	3.67				3.67 (530)
24	35.5	30.3	31.1	34.7	32.9 (4770)
168	44.9	39.7	42.6	45.3	43.1 (6250)
672	44.3	41.5	50.8	47.5	46.0 (6680)
Extended with 4.5 kg (10 lb) of River Gravel					
3	20.4	20.2	21.2		20.6 (2980)
24	43.4	36.8	40.9	38.0	39.8 (5770)
168	59.7	56.6	51.8	54.5	55.6 (8070)
672	61.6	56.8	61.2	55.4	56.7 (8230)

[1] 51-mm (2-in.) cubes; units of strength are MPa (psi).

Table C6
Compressive Strength[1] for Five Star Materials Cast and Cured at 2°C (35°F)

Curing Time (hrs)	Sample 1	Sample 2	Sample 3	Sample 4	Avg.
As-Received					
6	0.96	1.05	1.17	0.99	1.04 (150)
24	13.8	14.1	18.0		15.3 (2220)
168	27.9	29.2	26.6	26.9	27.7 (4010)
672	33.2	34.6	32.3	35.0	33.8 (4900)
Extended with 4.5 kg (10 lb) of River Gravel					
24	8.83	10.3	8.12		9.07 (1320)
72	28.4	25.7	29.1		27.7 (4020)
168	35.4	32.2	35.5		34.4 (4990)
672	40.4	42.7	42.2		41.7 (6060)

[1] 51-mm (2-in.) cubes; units of strength are MPa (psi).

Table C7
Compressive Strength[1] for Rapid Set Concrete Cast and Cured at 2°C (35°F)

Curing Time (hrs)	Sample 1	Sample 2	Sample 3	Sample 4	Avg.
6	0.86	0.75	0.67		0.76 (110)
24	31.1	30.9	26.8	30.8	29.9 (4340)
168	49.0	46.5	40.5	40.7	44.2 (6410)
672	55.7	52.2	54.8	57.0	54.9 (7970)

[1] 51-mm (2-in.) cubes; units of strength are MPa (psi).

Table C8
Compressive Strength[1] for Set-45 Materials Cast and Cured at 2°C (35°F)

Curing Time (hrs)	Sample 1	Sample 2	Sample 3	Sample 4	Avg.
As-Received					
3	9.46	9.09	7.86		8.81 (1280)
24	43.5	41.0	40.5		41.6 (6040)
168	40.6	44.2			42.4 (6150)
672	48.9	51.7			50.3 (7300)
Extended with 4.5 kg (10 lb) of River Gravel					
6	11.1	10.6	11.2		11.0 (1590)
24	35.2	33.7	30.9		33.2 (4820)
168	42.7	41.2	42.3		42.1 (6100)
672	45.7	40.1	42.2		42.7 (6190)

[1] 51-mm (2-in.) cubes; units of strength are MPa (psi).

Table C9
Compressive Strength[1] for Five Star Materials[2] Cast and Cured at 46°C (115°F)[3]

Curing Time (hrs)	Sample 1	Sample 2	Sample 3	Sample 4	Avg.
As-Received					
3	27.1	27.7	28.9		27.9 (4040)
24	38.0	39.7	40.2		39.3 (5700)
168	49.0	50.0	48.0	49.1	49.0 (7110)
672	49.6	50.2	52.1		50.6 (7340)
Extended with 4.5 kg (10 lb) of River Gravel					
3	29.7	30.2	29.8		29.9 (4340)
24	45.1	40.6	46.7	39.8	43.1 (6250)
168	53.4	58.6	55.3		55.8 (8090)
672	52.2	57.9	52.7	55.4	54.6 (7920)

[1] 51-mm (2-in.) cubes; units of strength are MPa (psi).
[2] Retarder: 3 tubes, 44 ml per 23-kg bag (1.5 fl oz per 50-lb bag).
[3] Mixing water temperature = 25°C (77°F).

Table C10
Compressive Strength[1] for Rapid Set Materials[2] Cast and Cured at 46°C (115°F)[3]

Curing Time (hrs)	Sample 1	Sample 2	Sample 3	Sample 4	Avg.
High Water Content, 5200 ml per 27 kg bag (5.5 qt per 60 lb bag)					
3	12.2	10.8	12.9		12.0 (1740)
24	25.4	25.2	25.4	25.3	25.3 (3670)
168	32.9	32.3	32.0		32.4 (4690)
672	29.9	31.2	33.2	32.3	31.7 (4590)
Low Water Content, 3790 ml per 27 kg bag (4.0 qt per 60 lb bag)					
3	29.9	29.9	32.8		30.8 (4470)
24	45.3	43.3	45.2		44.6 (6470)
168	50.7	49.3	53.1	50.3	50.9 (7380)
672	47.7	50.2	48.9	47.8	48.7 (7060)

[1] 51-mm (2-in.) cubes; units of strength are MPa (psi).
[2] Retarder: 1.5 packets, 51 gm per 27-kg bag (1.8 oz per 60-lb bag).
[3] Mixing water temperature = 25°C (77°F).

Table C11
Compressive Strength[1] for Set-45 Hot Weather Materials[2] Cast and Cured at 46°C (115°F)

Curing Time (hrs)	Sample 1	Sample 2	Sample 3	Sample 4	Avg.
As-Received and Mixing Water at 2°C (35°F)					
3	44.5	49.2	43.8	44.7	45.6 (6610)
24	49.9	51.3	57.5		52.9 (7670)
168	64.5	58.0	65.6		62.7 (9090)
672	65.1	60.2	61.6		62.3 (9030)
Extended with 4.5 kg (10 lb) of River Gravel and Mixing Water at 2°C (35°F)					
3	38.2	42.3	40.0		40.2 (5830)
24	60.7	57.4	60.8		59.6 (8650)
168	62.0	63.8	64.7		63.5 (9210)
672	65.1	63.9	62.7		63.9 (9260)
Extended with 4.5 kg (10 lb) of River Gravel and Mixing Water at 25°C (77°F)					
3	43.7	41.0	41.7		42.2 (6110)
24	47.4	52.0	51.2		50.2 (7280)

[1] 51-mm (2-in.) cubes; units of strength are MPa (psi).
[2] Retarder included by the manufacturer.

Table C12
Slant-Shear Bond Test[1] for Concrete Cast and Cured at 77°F (25°C)

Material	Condition[2]	Sample 1	Sample 2	Sample 3	Avg.
Five Star	Dry	31.6	28.3	29.6	29.8 (4330)
	Wet	22.9	23.0	22.3	22.7 (3300)
Five Star Extended	Dry	23.3	22.1	23.0	22.8 (3300)
	Wet	24.8	20.4	18.4	21.2 (3070)
Rapid Set	Dry	14.6	15.5	16.2	15.4 (2240)
	Wet	14.6	13.6	18.5	15.6 (2260)
Set-45	Dry	14.5	9.47	11.9	12.0 (1740)
	Wet	22.3	23.0	22.7	22.7 (3290)
Set-45 Extended	Dry	11.4	12.4	13.1	12.3 (1790)
	Wet	23.2	23.4	18.4	21.7 (3140)
Set-45 Hot Weather	Dry	11.1	18.4	16.0	15.2 (2210)
	Wet	8.98	12.4	16.9	12.8 (1850)
Set-45 Hot Weather Extended	Dry	6.25	6.82	5.19	6.09 (880)
	Wet	16.5	16.8	9.25	14.2 (2060)

[1] 76 x 152-mm (3 x 6-in.) cylinders, units of strength are MPa (psi); measured after 7 days of curing.
[2] Condition of surface against which repair material was cast.

Appendix D
Compatibility Characteristics

Table D1
Modulus of Elasticity[1] for Concrete Cast and Cured at 25°C (77°F)

Material	Sample 1	Sample 2	Sample 3	Avg.
Five Star	22.1	34.3	31.6	29.3 (4260)
Five Star Extended	37.8	39.7	42.6	40.1 (5810)
Rapid Set	17.0	19.6	24.3	20.3 (2950)
Set-45	35.7	21.8	29.0	28.8 (4180)
Set-45 Extended	25.4	33.6	25.6	28.2 (4090)
Set-45 Hot Weather	31.8	38.4	33.5	34.6 (5020)
Set-45 Hot Weather Extended	26.0	17.7	25.2	22.9 (3330)

[1] 76 x 152-mm (3 x 6-in.) cylinders, units of strength are GPa (ksi); measured after 7 days of curing.

Table D2
Coefficient of Thermal Expansion, mm/mm/°C x 10^{-6} (in/in/°F x 10^{-6})

Material	Sample 1	Sample 2	Sample 3	Average
Five Star	12.1	12.2	12.1	12.1 (6.7)
Five Star Extended	12.2	12.1	12.4	12.2 (6.8)
Rapid Set	12.9	13.1	13.3	13.1 (7.3)
Set-45	12.6	12.6	12.6	12.6 (7.0)
Set-45 Extended	11.9	12.4	12.2	12.2 (6.8)
Set-45 Hot Weather	12.8	12.6	12.9	12.8 (7.1)
Set-45 Hot Weather Extended	12.6	12.9	12.9	12.8 (7.1)

Appendix E
Durability Properties

Table E1
Freeze-Thaw Test Results (Procedure A)

Material	Number of Cycles[1]				Durability Factor
	sa. 1	sa. 2	sa. 3	Avg.	
Five Star	178	105	177	153	31
Rapid Set	11	10	9	10	2.0
Set-45	158	284	179	207	41
Set-45 Hot Weather	8	7	7	7	1.4

[1] At which relative dynamic modulus of elasticity fell to 60 percent (estimated by interpolation between measurements if needed).

Table E2
Length Change of Concrete After 28 Days of Curing in Air[1]

Material	Sample 1	Sample 2	Sample 3	Avg.
Five Star	-0.082	-0.074	-0.079	-0.078
Five Star Extended	-0.038	-0.046	-0.037	-0.040
Rapid Set	-0.022	-0.021	-0.019	-0.021
Set-45	-0.001	-0.001	-0.001	-0.001
Set-45 Extended	-0.004	-0.005	-0.005	-0.005
Set-45 Hot Weather	-0.011	-0.007	-0.009	-0.009
Set-45 Hot Weather Extended	-0.010	-0.010	-0.010	-0.010

[1] 76 x 76 x 286-mm (3 x 3 x 11-in.) prisms, units of length change are percent; initial length taken 3 hr after casting.

Table E3
Length Change of Concrete After 28 Days of Curing in Lime-Saturated Water[1]

Material	Sample 1	Sample 2	Sample 3	Avg.
Five Star	0.011	0.001	0.005	0.009
Five Star Extended	0.003	0.009	---	0.006
Rapid Set	0.019	0.015	0.015	0.016
Set-45	-0.005	-0.002	-0.002	-0.003
Set-45 Extended	0.005	0.005	0.006	0.005
Set-45 Hot Weather	-0.003	-0.003	-0.003	-0.003
Set-45 Hot Weather Extended	-0.002	-0.003	-0.002	-0.002

[1] 76 x 76 x 286-mm (3 x 3 x 11-in.) prisms, units of shrinkage are percent; initial length taken 3 hr after casting.

Appendix F
Material Fact Sheets

1. MATERIAL NAME (LATEST UPDATE)

Five Star® Highway Patch (September 1996)

2. MANUFACTURER

Five Star Products, Inc.
425 Stillson Road
Fairfield, CT 06430

general information	800-243-2206
engineering and technical support	203-336-7900
chemical emergency	800-255-3924
facsimile	203-336-7930

3. DESCRIPTION

Five Star® Highway Patch is a prepackaged dry mortar mix available in 22.7 kg (50 lb) bags. Five Star® Highway Patch contains an hydraulic cement, for which a patent is pending, and siliceous sand finer than 2.36 mm (No. 8 sieve).

Five Star Products also markets a set retarding admixture called Summerset®, which can be used with Five Star® Highway Patch. This admixture is an organic acid and is available in liquid form. Summerset® is packaged in 15-cc (1/2-fl oz) vials, which makes it convenient for use at various dosages with the 22.7 kg (50 lb) bags of Five Star® Highway Patch.

4. USES

Five Star® Highway Patch can be used as a partial-depth spall repair material for portland cement concrete pavements and slabs.

5. MANUFACTURER'S GUIDANCE FOR APPLICATION

Concrete surfaces onto which Five Star® Highway Patch will be placed should be soaked but free of standing water. Surfaces should be conditioned to between 2°C and 32°C (35°F and 90°F) at the time of placement.

Five Star® should be mixed in a mortar mixer, which should be charged in the following order: water, Five Star® Highway Patch, and if extending, then the aggregate. The maximum recommended amount of mixing water is 2840 ml (3 qt) per bag of material. The material can be extended with up to 13.6 kg (30 lb) of 6.4 to 12.7 mm (1/4 to 1/2 in.) dry gravel or crushed stone. Mixing should proceed for 2 to 5 min. The user should not mix more material than that which can be placed in 10 min. Once the Five Star® Highway Patch patch has hardened, it should be kept wet for a minimum of 1/2 hr.

In cold weather, Five Star® Highway Patch should be protected from freezing until a compressive strength of at least 6.9 MPa (1000 psi) is obtained. Faster strength gain will occur if the Five Star® Highway Patch and the mixing water are warmed prior to mixing and placement.

In hot weather, Five Star® Highway Patch should be kept as cool as possible [at least cooler than 32°C (90°F)]. Ice cold water and Summerset® retarder can be used to extend working times. Summerset® should be dispersed completely in the mixing water. A general guide for the use of Summerset® is to use one vial per bag of Five Star® Highway Patch for every 6°C (10°F) above 21°C (70°F). Up to 3 tubes may be added per bag.

6. EVALUATION BY U.S. ARMY ENGINEER WATERWAYS EXPERIMENT STATION (WES)

Based on workability considerations, the maximum amount of aggregate for extending the volume of a single 22.7 kg (50 lb) bag of Five Star® Highway Patch was judged to be 4.5 kg (10 lb). Based on a loose unit weight of 1440 kg/m^3 (90 lb/ft^3), this amount of aggregate would be approximately 3150 ml (3.3 qt) in volume. With this level of aggregate extension, each bag of Five Star® Highway Patch will produce approximately 0.01 m^3 (0.4 ft^3) of material. At 25°C (77°F), one bag of Five Star® Highway Patch, dry aggregate, and the maximum recommended amount of mixing water [2840 ml (3 qt)] will produce a concrete mix with a slump of approximately 230 mm (9 in.). Slump will change to 76 mm (3 in.) in approximately 45 min.

Personnel at WES tested this material for strength, compatibility with ordinary concrete, and durability. Strength tests included flexural, compressive, and bond strength. Compatibility tests included modulus of elasticity and coefficient of thermal expansion. Durability tests included resistance to freeze-thaw deterioration and volume changes with changes in moisture.

Properties of neat and extended mixtures, produced and cured at 25°C (77°F), are shown in Table 1. Compressive strengths for neat and extended mixtures produced at both cold [2°C (35°F)] and hot [46°C (115°F)]

temperatures are shown in Table 2. The cold mixtures were produced with water chilled to the same temperature. The hot mixtures were produced with room-temperature (25°C) mixing water. The water content of all mixtures was 2840 ml (3 qt) per 22.7 kg (50 lb) bag. The mixture placed in the hot environment included 3 tubes (45 ml) of Summerset® retarding admixture per 22.7 kg (50 lb) bag of Five Star® Highway Patch.

Field personnel are encouraged to produce trial mixtures with aggregate and Summerset® admixture (if applicable) in order to ensure that adequate workability and working time will be attained. These trial mixtures should not exceed the maximum water content recommended by Five Star and they should be produced under the climatic conditions that are anticipated for the spall repairs. The initial temperature of materials should be controlled to minimize risk of freezing or to extend working time.

Table 1
Mixtures Produced and Cured at 25°C (77°F)

Property	Neat Mixture	Extended Mixture[1]
Flexural Strength, MPa (psi) ASTM C 78 - 3 hours - 7 days	 3.33 (483) 3.71 (539)	 3.85 (560) 3.71 (540)
Compressive Strength, MPa (psi) ASTM C 109 - 3 hours - 1 day - 7 days - 28 days	 9.3 (1350) 42.0 (6100) 55.7 (8080) 58.6 (8500)	 3.2 (460) 51.0 (7390) 58.2 (8440) 68.5 (9930)
Bond Strength, MPa (psi) ASTM C 882 - dry substrate - wet substrate	 29.8 (4330) 22.7 (3300)	 22.8 (3300) 21.2 (3070)
Modulus of Elasticity, GPa (ksi) ASTM C 469 - 7 days	 29.3 (4260)	 40.1 (5810)
Coefficient of Thermal Expansion, mm/mm/°C (in./in./°F) x 10^{-6} CRD-C 39	 12.1 (6.7)	 12.2 (6.8)
Freeze-Thaw Durability Factor ASTM C 666 (Procedure A)	 31	 ---
Length Change in Air, percent ASTM C 157 (initial length at 3 hours)	 -0.078	 -0.040
Length Change in Water, percent ASTM C 157 (initial length at 3 hours)	 0.009	 0.006

[1] Extended with 4.5 kg (10 lb) of 6.4 to 12.7 mm (1/4 to 1/2 in.) dry gravel.

Table 2
Compressive Strength of Mixtures Produced and Cured Under Cold and Hot Conditions

Property	Neat Mixture	Extended Mixture[1]
Compressive Strength at 2°C (35°F), MPa (psi) ASTM C 109		
- 1 day	15.3 (2220)	9.07 (1320)
- 7 days	27.7 (4010)	34.4 (4990)
- 28 days	33.8 (4900)	41.7 (6060)
Compressive Strength at 46°C (115°F), MPa (psi) ASTM C 109		
- 3 hours	27.9 (4040)	29.9 (4340)
- 1 day	39.3 (5700)	43.1 (6250)
- 7 days	49.0 (7110)	55.8 (8090)
- 28 days	50.6 (7340)	54.6 (7920)

[1] Extended with 4.5 kg (10 lb) of 6.4 to 12.7 mm (1/4 to 1/2 in.) dry gravel.

7. MATERIAL HANDLING CONSIDERATIONS

Unopened bags should be stored under dry conditions. If the material is kept dry, the manufacturer estimates shelf-life at one year.

Cementitious material may cause irritation. Wash skin thoroughly after handling. Keep out of reach of children. Avoid contact with eyes and prolonged contact with skin. In case of contact with eyes, immediately flush with plenty of water for at least 15 min. Call a physician.

8. COST

In the year 1996, the cost of Five Star® Highway Patch was approximately \$20 per 22.7 kg (50 lb) bag. The cost of Summerset® retarding admixture was approximately \$2.50 per 15 cc (1/2 fl oz) tube.

9. POINTS OF CONTACT

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3909 Halls Ferry Road
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1. MATERIAL NAME (LATEST UPDATE)

Rapid Set® Concrete Mix (September 1996)

2. MANUFACTURER

CTS Cement Manufacturing Company
11065 Knott Ave., Suite A
Cypress, CA 90630

general information	714-379-8260
technical hotline	800-929-3030
order desk	800-523-6368
facsimile	714-379-8270

3. DESCRIPTION

Rapid Set® Concrete Mix is packaged dry in 60 lb (27.2 kg) bags. It contains Rapid Set® Cement, which is a hydraulic cement with high chemical contents of alumina and sulfur trioxide. The manufacturer states that its composition is similar to that of ASTM C 845 Type K expansive cement, which is used in shrinkage-compensating concrete. Rapid Set® Concrete Mix also contains siliceous sand and crushed limestone aggregate particles all finer than 19.1 mm (3/4 in.) size.

The CTS Company markets a set retarding admixture called Set Control™. This admixture, which is an organic (citric) acid, is available in dry powder form. The product is packaged in bags that contain approximately 30 gm of material, which makes it convenient for use in various amounts with the 27.2 kg (60 lb) bags of Rapid Set® Concrete Mix.

4. USES

Rapid Set® Concrete Mix can be used as a partial-depth spall repair material for portland cement concrete pavements and slabs.

5. MANUFACTURER'S GUIDANCE FOR APPLICATION

Concrete surfaces onto which Rapid Set® Concrete will be placed should be dampened with water. The maximum recommended quantity of mixing water ranges from 2840 ml (3 qt) to 5200 ml (5-1/2 qt), depending on placement temperature. The maximum recommended water content should not be exceeded. Partial bags should not be used due to the possibility of segregation of the aggregate. Directions on the Rapid Set® bags state that curing after placement is not required. However, other product literature recommends the use of a curing compound or the maintenance of surface moisture for at least one hour after placement.

For hot weather applications, the manufacturer recommends the use of Set Control™ retarding admixture. The manufacturer also suggests cooling concrete materials to extend the working time.

6. EVALUATION BY U.S. ARMY ENGINEER WATERWAYS EXPERIMENT STATION (WES)

One bag of Rapid Set® Concrete Mix will produce approximately 0.01 m^3 (0.4 ft^3) of concrete. At 25°C (77°F), the maximum recommended amount of mixing water [3790 ml (4 qt)] will produce a concrete mix with a slump of approximately 230 mm (9 in.). Slump will change to 76 mm (3 in.) in approximately 40 min.

Personnel at WES tested this material for strength, compatibility with ordinary concrete, and durability. Strength tests included flexural, compressive, and bond strength. Compatibility tests included modulus of elasticity and coefficient of thermal expansion. Durability tests included resistance to freeze-thaw deterioration and volume changes with changes in moisture.

Properties of concrete produced and cured at 25°C (77°F) are shown in Table 1. Compressive strengths for mixtures produced at both cold [2°C (35°F)] and hot [46°C (115°F)] temperatures are shown in Table 2. The cold mixtures were produced with water chilled to the same temperature. The hot mixtures were produced with room-temperature (25°C) mixing water. The mixtures placed in the hot environment included 1.5 packets (45 gm) of Set Control® admixture per 27-kg (60-lb) bag of Rapid Set® Concrete Mix.

The adjusted water contents recommended by the manufacturer for cold and hot placement temperatures were not acceptable. At 2°C (35°F), the recommended water content of 2840 ml (3 qt) did not provide sufficient workability. At 46°C (115°F), the recommended water content of 5200 ml (5.5 qt) produced a "soupy" mixture. Therefore, the water content of all mixtures was 3790 ml (4 qt) per 27.2 kg (60 lb) bag.

Table 1
Mixtures Produced and Cured at 25°C (77°F)

Property	Result
Flexural Strength, MPa (psi) ASTM C 78 - 3 hours - 7 days	 3.27 (480) 3.61 (520)
Compressive Strength, MPa (psi) ASTM C 109 - 3 hours - 1 day - 7 days - 28 days	 26.6 (3860) 46.4 (6730) 54.8 (7950) 56.9 (8260)
Bond Strength, MPa (psi) ASTM C 882 - dry substrate - wet substrate	 15.4 (2240) 15.6 (2260)
Modulus of Elasticity, GPa (ksi) ASTM C 469 - 7 days	 20.3 (2950)
Coefficient of Thermal Expansion, mm/mm/°C (in./in./°F) x 10^{-6} CRD-C 39	 13.1 (7.3)
Freeze-Thaw Durability Factor ASTM C 666 (Procedure A)	 2.0
Length Change in Air, percent ASTM C 157 (initial length at 3 hours)	 -0.021
Length Change in Water, percent ASTM C 157 (initial length at 3 hours)	 0.016

Table 2 Compressive Strength of Mixtures Produced and Cured Under Cold and Hot Conditions	
Property	**Result**
Compressive Strength at 2°C (35°F), MPa (psi) ASTM C 109 - 1 day - 7 days - 28 days	 29.9 (4340) 44.2 (6410) 54.9 (7970)
Compressive Strength at 46°C (115°F), MPa (psi) ASTM C 109 - 3 hours - 1 day - 7 days - 28 days	 30.8 (4470) 44.6 (6470) 50.9 (7380) 48.7 (7060)

Field personnel are encouraged to produce trial mixtures with Rapid Set® Concrete and Set Control® admixture (if applicable) in order to ensure that adequate workability and working time will be attained. These trial mixtures should not exceed the maximum water content recommended by CTS Cement Manufacturing Co. and they should be produced under the climatic conditions that are anticipated for the spall repairs. The initial temperature of materials can be controlled to minimize risk of freezing or to extend working time.

7. MATERIAL HANDLING CONSIDERATIONS

Unopened bags should be stored under dry conditions. The manufacturer warns that the shelf life of an unopened bag of Rapid Set® Concrete is approximately one year.

Rapid Set® Concrete Mix contains cementitious materials. Freshly mixed concrete may cause skin irritation. Avoid direct contact where possible and wash exposed skin areas promptly with water. If any cementitious material gets into the eye, rinse immediately and repeatedly with water and get prompt medical attention.

8. COST

In the year 1996, the cost of Rapid Set® Concrete Mix was approximately \$15 per 27.2 kg (60 lb) bag and the cost of Set Control™ retarding admixture was approximately \$1 per 30-gm packet.

9. POINTS OF CONTACT

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1. MATERIAL NAME (LATEST UPDATE)

Set-45® and Set-45® Hot Weather (September 1996)

2. MANUFACTURER

Master Builders, Inc.
23700 Chagrin Boulevard
Cleveland, OH 44122

general information	216-831-5500
general information	800-628-7378
chemical emergency	800-424-9300
facsimile	216-831-6910

3. DESCRIPTION

Set-45® is packaged as a dry mortar in 22.7 kg (50 lb) bags. Set-45® contains magnesium phosphate cement and siliceous sand. All particles in the as-received material are finer than 2.36 mm (No. 8 sieve).

Set-45® Hot Weather is marketed by Master Builders as a special formulation of Set-45® designed for placements in hot weather. Similar to the standard formulation of Set-45®, Set-45® Hot Weather is packaged in 22.7 kg (50 lb) bags and all of its particles are finer than 2.36 mm (No. 8 sieve). The hot weather formulation contains a chemical admixture for retardation of hydration reactions.

4. USES

Set-45® and Set-45® Hot Weather can be used as partial-depth spall repair materials for portland cement concrete pavements and slabs.

5. MANUFACTURER'S GUIDANCE FOR APPLICATION

Concrete surfaces onto which either Set-45® or Set-45® Hot Weather will be placed should be dry for best bond. With the combination of the two formulas, placement temperatures range from 2°C to 38°C (35°F to 100°F). Set-45® should be mixed in a mortar mixer. The mixer should be charged in the following order: water, aggregate (if extending), and Set-45®. The ingredients should be mixed for 1 to 1-1/2 min. At 22°C (72°F), ten min is available for mixing, placing, and finishing the standard formula of Set-45®. At high temperatures [29°C to 38°C (85°F to 100°F)], ten min are allowed to mix, place and finish Set-45 Hot Weather. Longer mixing and placing times occur when using Hot Weather formula in cooler temperatures. The user should not deviate from the water contents recommended on the bags: 1900 ml of water per 22.7 kg (50 lb) bag of Set-45® and 1800 ml of water per 22.7 kg bag of

Set-45® Hot Weather. The material can be extended with up to 13.6 kg (30 lb) of 6.4 to 12.7 mm (1/4 to ½ in.) dry gravel. When using angular aggregate, reduce the maximum amount added to 11.4 kg (25 lb). Do not use calcareous aggregates. The manufacturer states on the bag that the repair should air dry for proper cure. Do not wet cure. Plastic sheeting or curing compounds may be used if they are needed for protection against climatic elements.

In cold temperatures [below 4°C (40°F)], the concrete surface should be warmed prior to placing Set-45® regular formulation. The use of warm mixing water [32°C (90°F)] will increase the rate of hardening. For hot weather applications, use Set-45® Hot Weather formulation and aggregate extension if possible. The use of cold mixing water will also extend the working time. If the concrete surface to be repaired is hot, it should be cooled with shade and/or fine mist, but avoid ponding water. Hot surfaces will hinder bond.

6. EVALUATION BY U.S. ARMY ENGINEER WATERWAYS EXPERIMENT STATION (WES)

Based on workability considerations, the maximum amount of aggregate for extending the volume of a single 22.7 kg (50 lb) bag of Set-45® was judged to be 4.5 kg (10 lb). Based on a loose unit weight of 1440 kg/m^3 (90 lb/ft^3), this amount of aggregate would be approximately 3150 ml (3.3 qt) in volume. With this level of aggregate extension, each bag of Set-45® will produce approximately 0.01 m^3 (0.4 ft^3) of material. At 25°C (77°F), one bag of Set-45®, dry aggregate, and the recommended amount of mixing water [1900 ml (2 qt)] will produce a concrete mix with a slump of approximately 230 mm (9 in.). Slump will change to less than 76 mm (3 in.) in approximately 15 min. Under the same conditions, but with its recommended water content of 1800 ml (1.9 qt), Set-45® Hot Weather will produce approximately the same initial slump and the slump will remain greater than 76 mm for approximately 50 min.

Personnel at WES tested this material for strength, compatibility with ordinary concrete, and durability. Strength tests included flexural, compressive, and bond strength. Compatibility tests included modulus of elasticity and coefficient of thermal expansion. Durability tests included resistance to freeze-thaw deterioration and volume changes with changes in moisture.

Properties of neat and extended mixtures, produced and cured at 25°C (77°F), are shown in Tables 1 and 2. Set-45® was used for the mixtures shown in Table 1 and Set-45® Hot Weather was used for the mixtures in Table 2. Compressive strengths for neat and extended mixtures produced at a cold [2°C (35°F)] temperature with Set-45® are shown in Table 3. Compressive strengths for neat and extended mixtures produced at a hot [46°C (115°F)] temperature with Set-45® Hot Weather are shown in Table 4. The cold mixtures were produced with water at the same temperature and the hot mixtures required the mixing water to be cooled to 2°C in order to permit at least 15 min of working time. The water content of all Set-45® mixtures was 1900 ml (2 qt) per 22.7 kg (50 lb) bag. The water content of all Set-45® Hot Weather mixtures was 1800 ml (1.9 qt) per 22.7 kg (50 lb) bag.

Field personnel are encouraged to produce trial mixtures with aggregate in order to ensure that adequate workability and working time will be attained. These trial mixtures should not exceed the maximum water content recommended by Master Builders and they should be produced under the climatic conditions that are anticipated for the spall repairs. The initial temperature of materials should be controlled to minimize risk of freezing or to extend working time.

Table 1
Set-45® Mixtures Produced and Cured at 25°C (77°F)

Property	Neat Mixture	Extended Mixture[1]
Flexural Strength, MPa (psi) ASTM C 78 - 3 hours - 7 days	 3.05 (440) 3.59 (520)	 3.03 (440) 3.52 (510)
Compressive Strength, MPa (psi) ASTM C 109 - 3 hours - 1 day - 7 days - 28 days	 45.2 (6550) 46.4 (6730) 50.5 (7320) 68.1 (9870)	 43.9 (6370) 47.0 (6820) 49.0 (7100) 63.1 (9150)
Bond Strength, MPa (psi) ASTM C 882 - dry substrate - wet substrate	 12.0 (1740) 22.7 (3290)	 12.3 (1790) 21.7 (3140)
Modulus of Elasticity, GPa (ksi) ASTM C 469 - 7 days	 28.8 (4180)	 28.2 (4090)
Coefficient of Thermal Expansion, mm/mm/°C (in./in./°F) x 10^{-6} CRD-C 39	 12.6 (7.0)	 12.2 (6.8)
Freeze-Thaw Durability Factor ASTM C 666 (Procedure A)	 41	 ---
Length Change in Air, percent ASTM C 157 (initial length at 3 hours)	 -0.001	 -0.005
Length Change in Water, percent ASTM C 157 (initial length at 3 hours)	 -0.003	 0.005

[1] Extended with 4.5 kg (10 lb) of 6.4 to 12.7 mm (1/4 to ½ in.) dry gravel.

Table 2
Set-45® Hot Weather Mixtures Produced and Cured at 25°C (77°F)

Property	Neat Mixture	Extended Mixture[1]
Flexural Strength, MPa (psi) ASTM C 78 - 3 hours - 7 days	 3.46 (500) 3.78 (550)	 3.40 (493) 3.67 (532)
Compressive Strength, MPa (psi) ASTM C 109 - 3 hours - 1 day - 7 days - 28 days	 3.0 (440) 32.9 (4770) 43.1 (6250) 46.0 (6680)	 20.6 (2980) 39.8 (5770) 55.6 (8070) 56.7 (8230)
Bond Strength, MPa (psi) ASTM C 882 - dry substrate - wet substrate	 15.2 (2210) 12.8 (1850)	 6.09 (880) 14.2 (2060)
Modulus of Elasticity, GPa (ksi) ASTM C 469 - 7 days	 34.6 (5020)	 22.9 (3330)
Coefficient of Thermal Expansion, mm/mm/°C (in./in./°F) x 10^{-6} CRD-C 39	12.8 (7.1)	12.8 (7.1)
Freeze-Thaw Durability Factor ASTM C 666 (Procedure A)	1.4	---
Length Change in Air, percent ASTM C 157 (initial length at 3 hours)	-0.009	-0.010
Length Change in Water, percent ASTM C 157 (initial length at 3 hours)	-0.003	-0.002

[1] Extended with 4.5 kg (10 lb) of 6.4 to 12.7 mm (1/4 to ½ in.) dry gravel.

Table 3
Compressive Strength of Set-45® Mixtures Produced and Cured at 2°C (35°F)

Property	Neat Mixture	Extended Mixture[1]
Compressive Strength, MPa (psi)		
ASTM C 109		
- 3 hours	8.81 (1280)	---
- 1 day	41.6 (6040)	33.2 (4820)
- 7 days	42.4 (6150)	42.1 (6100)
- 28 days	50.3 (7300)	42.7 (6190)

[1] Extended with 4.5 kg (10 lb) of 6.4 to 12.7 mm (1/4 to ½ in.) dry gravel.

Table 4
Compressive Strength of Set-45® Hot Weather Mixtures Produced and Cured at 46°C (115°F)

Property	Neat Mixture	Extended Mixture[1]
Compressive Strength, MPa (psi)		
ASTM C 109		
- 3 hours	45.6 (6610)	40.2 (5830)
- 1 day	52.9 (7670)	59.6 (8650)
- 7 days	62.7 (9090)	63.5 (9210)
- 28 days	62.3 (9030)	63.9 (9260)

[1] Extended with 4.5 kg (10 lb) of 6.4 to 12.7 mm (1/4 to ½ in.) dry gravel.

7. MATERIAL HANDLING CONSIDERATIONS

Unopened bags should be stored under dry conditions. Expiration dates are printed on the packages. These dates appear to be approximately 6 months after manufacture for Set-45® and one year after manufacture for the Set-45® Hot Weather.

When mixing or placing Set-45® products in a closed area, provide adequate ventilation. These products can irritate eyes, skin, and lungs, so field personnel should wear protective eyewear, protective clothing, and suitable respiratory protection. Exposed skin should be washed with soap and water and irritated eyes should be flushed with large quantities of water. If breathing becomes difficult, personnel should move to an area that has fresh air.

This product is not listed as a hazardous waste in federal regulations, so it can be disposed in landfills in accordance with local regulations.

8. COST

In the year 1996, the cost of Set-45® was approximately $25 per bag and the cost of Set-45® Hot Weather was approximately $45 per bag.

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13. ABSTRACT *(Maximum 200 words)*

Three rapid-hardening, cement-based materials were evaluated for their effectiveness in repairing partial-depth concrete pavement spalls. The materials included Five Star® Highway Patch, Rapid Set®Concrete, and Master Builders Set-45®. The evaluations included both laboratory and field testing. Recommendations are provided for material selection for future projects. These recommendations are dependent on placement temperature and allowable curing duration, prior to opening the repaired area to traffic. Recommendations are also provided for test methods to be included in similar future evaluations of cementitious spall repair materials.

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